American-Eurasian J. Agric. & Environ. Sci., 23 (3): 99-105, 2023
ISSN 1818-6769

DOI: 10.5829/idosi.aejaes.2023.99.105

Effect of Legume Precursor Crop Stubble Management and Nitrogen Rate on Tef Yield and Physico-Chemical Properties of Vertisols

Negessa Gadisa, Abdisa Mekonnen and Aleminesh Sisay

Ethiopian Institute of Agricultural Research,
Holeta Agricultural Research Center, P.O. Box 2003, Holeta, Ethiopia

Abstract: Use of cropping system with optimum fertilizer is considered as the best practice for crop production in a sustainable way. A two-year field experiment was examined to evaluate the residual effects of nutrient N from legume precursors and level of nitrogen from chemical fertilizer on yield and soil fertility improvement during 2018-2022 main cropping seasons. A randomized complete block design with a split plot arrangement with three replications was used. The main plots were precursor crops and Subplots were different rates of nitrogen fertilizer practice. Data was collected on plant height, spike length, grain yield and biomass yield. Data was subjected to the general analysis of variance using R software version 4.2. Mean separation was calculated using the least significant difference LSD at a 5% probability level. The results revealed that main effect and interaction effect of precursor crop and nitrogen rates significantly ($P < 0.05$) influenced plant height spike length, biological yield and grain yield. The average total nitrogen available phosphorous and organic carbons content of the soil were significantly influenced by use of different precursor crop and nitrogen rates combination, indicating that precursor and nitrogen fertilizer can contribute to yield and yield components. Therefore, the use of precursor chickpea with straw together with and full recommended rate of nitrogen fertilizer could be the best option for both enhancing soil condition and improving tef yield under vertisol condition.

Key words: Precursor Crop · Tef · Nitrogen Fertilizer · Cropping System · Vertisol

INTRODUCTION

Tef is indigenous cereal specie in Ethiopia, ranking first in terms of national cereal grain production and consumption [1]. It is known for its nutritional value and adaptability to various environments, including highland Vertisols, which are characterized by their potential for agriculture but can present challenges related to soil management.Tef is sown on more than 1.7 million ha annually and is produced exclusively by peasant farmers within a labor-intensive farming system [2-4].

The productivity of crops is significantly influenced by soil fertility. Highland Vertisols, while having potential for high yields, might also suffer from waterlogging which cause nutrient inbalance and deficiencies [5]. Beside this, diffirent study had indicated nutrient loss due to biomass energy consumption of dung and crop residues which otherwise added to the soil is equivalent to the total amount commercial fertilizer use in high land vertisol recommending application of mineral fertilizer for cereal crops [6, 7].

Legume crops have the ability to fix atmospheric nitrogen into the soil through symbiotic relationships with nitrogen-fixing bacteria. The choice of legume precursor crop and its management can affect the availability of nitrogen for the subsequent tef crop [8]. Proper nitrogen management is crucial for optimizing crop growth and yield without causing environmental issues [9] and Understanding how different agricultural practices impact soil fertility and subsequently crop yield is essential for sustainable food production in the face of population growth and climate change [10, 11].

Optimum nutrient rate recommendations have been developed for the major cereal crops grown in Ethiopia and there has been some effort to give site specific fertilizer recommendation and to update previous

Correspondent Author: Negessa Gadisa, Ethiopian Institute of Agricultural Research,
Holeta Agricultural Research Center P.O. Box 2003, Holeta, Ethiopia.

recommendations. The need to adapt fertilizer technologies to local conditions is further dictated by the high fertilizer prices. Because of the high cost of fertilizers, their application should be extremely effective in raising physical yield, so as to ensure profitability. Reports of different scholars approved that Legumes have proven to increase crop yields of subsequent cereals remarkably as well as increasing the efficiency of mineral fertilizer uptake [12, 13]. But the nutrient added for the succeeding crop should be quantified to decrease the fertilizer addition for cereals. This study could provide insights into practices that enhance crop yield while minimizing negative impacts on the environment, such as excessive fertilizer use leading to nutrient runoff.

While there is existing research on tef cultivation, the specific interaction between legume precursor crop stubble management, nitrogen rates, soil properties and tef yield in highland Vertisols might not have been extensively studied. Therefore, the objective of this study was to determine the residual effects of nutrient N from legume precursor stable managemetnt and nitrogen fertilizer rate from chemical fertilizer on tef yield and soil fertility improvement.

MATERIALS AND METHODS

Description of the Study Site: The experiment was conducted at Ginchi sub center in the central part of Ethiopia. Ginchi sub center is located at 75 km west of Addis Ababa on the way to Ambo. It is situated at 9°02'N latitude and 38°12'E longitude with an elevation of 2200 m above sea level and receives average annual rainfall of 1095 mm, average relative humidity of 58.2% and average maximum and minimum air temperature of 24.6°C and 8.4°C respectively. The soil of the area is predominantly black clay Vertisol.

Experimental Design, Treatments and Field Management: The experiment was conducted at Ginchi sub-station during main cropping season in a permanent plot for two consecutive years. First, the whole field was planted with tef without any application of fertilizer to get uniform experimental field. Then, on the second year, legumes were planted with recommended seed rate, phosphorus and bio- fertilizer on recommended bed under waterlogged Vertisol (BBF). At harvest, the plots were divided into two to keep the residues on one half and remove from the other half. The performances of legume crops were checked before proceeding to the next seasons experiment. The residue that harvested from plot were returned to plots and incorporated to the soil after trashing. At the third year, plots were prepared manually in order not to mix the soil and then the sub plot treatments. Improved variety of Tef was planted in rows with 20 cm spacing.

Main plots	Sub plot
1. Chickpeas with residue - Tef	1. Control without fertilizer
2. Chick peas without residue - Tef	2. 0 kg N ha^{-1} + balanced
3. Lentil with residue -Tef	3. 50% kg N ha^{-1}+ balanced
4. Lentil without residue- Tef	4. 75% kg N ha^{-1}+ balanced
5. Tef-Tef	5. 100% kg N ha^{-1}+ balanced

The treatments were laid out in split plot design with three replications. The main plots were legume precursor crops with/without residue and the subplots were factorial combination of crop residues with nitrogen fertilizer rate. The plot size for the legumes was 19m by 3m. Further each plot was dividing in to two (9.5m x 3m) during harvest so that the residues were kept on one half of the plot and the removed from the other half (farmers practice). In the third year, the plot was further divided into five parts (3m x 1.5m) to study the effect of nitrogen fertilizer on tef productivity under balanced fertilizers. Each sub plot was received 0, 50%, 75% and 100% of recommended N from urea and based on Ethiosis maps other nutrients were applied equally to all plots.

Soil Sampling and Analysis: Soil samples were taken both before and after planting from the experimental field. Disturbed (using auger) soil samples which were composited by thoroughly mixing and undisturbed (using core) one was also collected. Before planting, disturbed samples were randomly taken from five different spots across each block from a depth of 0-20 cm to make one composite sample. After harvesting (five months later), soil samples were collected from each plot at a depth of 0-20 cm. The collected soil samples were bagged, labeled and submitted to the Holeta Agricultural research laboratory. In the laboratory sufficient amount of composite soil samples were air dried and ground to pass a 2-mm sieve except for organic carbon and total N in which 0.5 mm sieve was used. Then, soil samples were analyzed for physicochemical properties following standard laboratory procedures.

The pH of the soil was measured from suspension of 1: 2.5 (weight / volume) soil to water ratio using a glass electrode attached to digital pH meter [14]. Organic carbon content was determined using the Walkley and Black [15] wet digestion method. Total Nitrogen content was determined by the Kjeldahl digestion [16]. Available Phosphorus was extracted using Bray-II method [17]. The P extracted with this method was measured by spectrophotometer following the procedures described by Murphy and Riley [18].

Agronomic Data Collection: Days to heading were determined as the number of days from the date of sowing to the stage when 50% of the spikes fully emerged (headed). Days to maturity were estimated visually as the number of days from sowing to the stage when 90% of the plants in a plot reached physiological maturity. Plant height was measured from five pre-tagged plants from the base of the plant to the tip of the spike (awns excluded) by a meter rod. Averages of five plants were taken to compute mean plant height. Numbers of productive tillers were counted as the number of productive tillers per plant from five randomly selected plants pre- tagged from the net plot. Five spikes were selected randomly and spike length was measured. Figures of all the five spikes were added and the sum was divided by five to get average spike length in centimeter. Thousand grain weight was determined for each plot using electronic seed counter in three replications by weighing 1000 randomly selected grains and their average weight were recorded in grams. Wheat crop was harvested by collecting the above ground plant mass from the central $4.14m^2$ area of each plot when the plant showed clear signs of maturity (complete yellowing of leaves and spikes). Total above ground plant biomass (biological yield) obtained was dried up to lose the moisture content, for two weeks, in open air and weighed. Then, the weight was converted into t ha^{-1}. Grain yield was recorded after separating grain from straw yield of each net plot.

Statistical Analysis: All soil and agronomic data were subjected to statistical analysis of variance using a generalized linear model (GLM) in R statistical software version 3.5.3 R Core Team [19]. Significance of the treatments was tested using the agricolae package of R [20]. The means were compared using the lsmean package of R [21] with Duncan Multiple Range Test (DMRT) set at a 5% level of significance.

RESULTS AND DISCUSSION

Soil Physicochemical Properties of the Experimental Site Before Planting: The results of laboratory analysis for soil physical and chemical properties were presented in Table 1 for composited soil sample collected from (0-30 cm) before planting. The results indicated that soil texture was dominated by clay (65.80%) followed by silt (20.90%) and sand (13.30%). The dominance of clay in the experimental soil shows the opportunity of holding high exchangeable cations for crop growth. However, such characteristics of soil may be prone to either water logging or erosion unless properly managed [22]. The mean soil pH of the experimental site was 6.23. Based on the rating of Tekalign [23] the soil pH is rated as slightly acidic. According to FAO [24], the preferable pH ranges for most crops and productive soils are between 4 and 8 range. Soil organic carbon and total nitrogen content were 0.11 and 1.45 percent which classified into low range as suggested by Tekalign [25]. Soils that are tilled frequently like this site are usually low in organic carbon content because tilling decrease soil organic carbon content which adversely affects soil fertility unless organic source added timely. Similarly; available phosphorus in soil was 10.47. It was found in the medium range as suggested by Cottenie [26]. The cation exchange

Table 1: Average soil analytical results of the experimental site before planting

Parameters	Block-1	Block-2	Block-3	Mean
Clay (%)	65.80	64.90	65.70	65.47
Silt (%)	20.90	21.30	20.80	21.00
Sand (%)	13.30	13.80	13.50	13.53
pH (H_2O)	6.30	6.20	6.20	6.23
OC (%)	1.02	1.04	1.11	1.06
TN (%)	0.12	0.12	0.11	0.12
av. P(ppm)	10.50	9.85	11.07	10.47
CEC (meq/100kg)	52.64	49.12	53.25	51.67
Ca (meq/100kg)	34.29	35.13	34.18	34.53
K (meq/100kg)	1.32	1.21	1.35	1.29
Mg (meq/100kg)	14.87	13.43	14.06	14.12
Na (meq/100kg)	0.12	0.11	0.11	0.11

pH-Power of hydrogen; OC-Organic Carbon; TN-Total Nitrogen; av. P-Available Phosphorous; CEC-Cation Exchange

Table 2: Effect of different precursor crops on soil chemical properties after harvesting

Treatments	pH	TN (%)	OC (%)	Av. P (ppm)	K meq/100g	Mg meq/100g	Ca meq/100g	CEC meq/100g
CpS-Tef	6.36	0.17[ab]	1.150[a]	11.7	1.43	16.7	32.87	54.31
Cp-Tef	6.42	0.15[b]	1.10[b]	11.48	1.36	16.37	31.95	54.41
LT S-Tef	6.32	0.18[a]	1.150[a]	12.6	1.45	16.17	33.17	55.49
LT-Tef	6.38	0.16[ab]	1.10[b]	11.2	1.39	14.85	32.7	54.79
Tef-Tef	6.4	0.16[ab]	1.13[ab]	10.52	1.44	16.12	31.56	55.83
LSD (0.05)	NS	0.015	0.06	NS	NS	NS	NS	NS
CV (%)	1.2	7	4.3	8.3	6	6	4.5	2.9

Means in a column with different letters are significantly different at p ≤ 0.05; CpS- chickpea with residue; Cp-chickpea by removing residue Lt-lentil with residue; Lt-lentil by removing residue; OC-Organic Carbon; TN-Total Nitrogen; av. P-Available Phosphorous; CEC-Cation Exchange capacity; LSD - Least Significant Difference; CV- Coefficient of Variation; NS-Non-Significant at p ≤ 0.05.

Table 3: Influence of precursor straw management and nitrogen fertilizer interaction underbalanced fertilizer on tef grain yield in the year of 2021

	Nitrogen fertilizer rate (kg/ha)				
Straw management	0F	0N	50% RN	75% RN	100% RN
Chickpea with straw	570[h]	648[f-h]	1418[bc]	1662[ab]	1900[a]
Chickpea without straw	500[h]	632[f-h]	1031[de]	1255[c-e]	1579[a-c]
Lentil with straw	883[e-h]	905[e-h]	1033[d-f]	1488[bc]	1735[ab]
Lentil without straw	554[h]	609[gh]	1017[de]	1308[cd]	1524[bc]
Tef-Tef	495[h]	535[h]	940[e-g]	1243[c-e]	1458[bc]
$LSD_{0.05}$	120				
CV (%)	10.7				

Treatments with the same letter are not significantly different at p < 0.05; N-nitrogen, RN-recommended nitrogen fertilizer

capacity of the soil (51.67 meq/100kg) was classified into very high range as rated by Landon [27]. This could be due to dominance of the soil of the study area by smectite mineral group which can bear high exchangeable cations.

Effect of Precursor Crops on Soil Chemical Properties after Harvesting: The main effect of precursor crop has significantly (P < 0.05) influenced soil organic carbon and total nitrogen (Table 2). However, the main effect of nitrogen as well as the interaction effect of precursor crop and nitrogen fertilizer didn't significantly (P ≥ 0.05) affect Soil pH, available phosphorus (P) and exchangeable bases (Ca, Mg, K and N) although the existence of improvement observed relative to control.

Nitrogen is commonly deficient in vertisol areas. Total nitrogen, which is a primary nutrient that limit the growth of crop, was in the range of 0.15 to 0.17% after pre cursor crop had harvested. The highest value of soil total nitrogen (0.17%) was recorded from plots planted with chickpea crop whose straw was conserved on the plot while minimum value was the lowest value (0.15%) of total nitrogen was recorded from farmer practice which is continuous cultivation of tef. It was observed that there is significant improvement of total nitrogen after harvest of tef crop. According to Berhanu [28], the soil total nitrogen values was found in low range. The highest soil organic carbon (1.15 %) were obtained from the use of chickpea precursor crop when used with straw material while minimum value (1.13) was obtained from control. The increment of soil organic carbon content over the control could be due to improvement of soil physical properties that help to increase soil biota which facilitate conversion of straw material to organic soil. Application of organic source could be resulted in improvement of soil organic matter content [29, 30]. Significant improvement of soil organic carbon content was observed organic source materials appliedwith chemical fertilizer [31-33].

Effects of Legume Precursor and Nitrogen Fertilizer on tef Yield and Yield Components: The analysis of variance showed that the main effect of precursor cropstraw management and nitrogen fertilizer as well as the interaction of precursor straw management with nitrogen fertilizer rate were significantly (P< 0.05) affected tef grain and biomass yield (Table 3 and Table 4) during cropping season of 2021 and 2022. Conservation of precursor residue improved grain yield and biomass of tef relative to plot without precursor crop residues conservation. Both biomass and grain yield exhibited an increasing trend with the increased level of nitrogen fertilizer rate. The highest tef biomass (5630 kg ha^{-1}) and grain yield (1900 kg ha^{-1}) were respectively recorded from plot that treated with recommended nitrogen rate and chickpea straw conservation even though statistically par with lentil straw conserved plot during 2021 cropping season. However, minimum values of biomass and grain yield were obtained from plot cultivated with continuous tef without fertilizer application.

Table 4: Influence of precursor straw management and nitrogen fertilizer interaction under balanced fertilizeron tef biomass yield in the year of 2021

	Nitrogen fertilizer rate(kg/ha)				
Straw Management	0F	0N	50% RN	75% RN	100% RN
Chickpea with straw	2296^{h-k}	2185^{i-k}	3815^{b-g}	4778^{a-c}	5630^{a}
Chickpea without straw	1926^{jk}	2452^{g-k}	3259^{d-j}	3852^{b-f}	4815^{a-c}
Lentil with straw	3556^{c-i}	3778^{b-g}	3630^{c-h}	4889^{a-c}	5074^{ab}
Lentil without straw	2667^{f-k}	2815^{e-k}	3778^{b-g}	4185^{b-e}	4741^{a-c}
Teff	1852^{k}	2037^{jk}	3593^{c-h}	3963^{b-f}	4407^{a-d}
$LSD_{0.05}$	1378				
CV (%)	12				

Treatments with the same letter are not significantly different at $p < 0.05$; N-nitrogen, RN-recommended nitrogen fertilizer

Table 5: Influence of precursor straw management and nitrogen fertilizer on tef grain yield and yield components in the year of 2022

	Nitrogen fertilizer rate(kg/ha)				
Straw management	0F	0N	50% RN	75% RN	100% RN
Chickpea with straw	808^{i-m}	1063^{f-j}	1439^{d-f}	1922^{a-c}	2371^{a}
Chickpea without straw	708^{j-m}	996^{f-l}	1036^{f-k}	1536^{c-e}	2007^{ab}
Lentil with straw	544^{lm}	966^{g-l}	1418^{d-g}	1931^{a-c}	2332^{a}
Lentil without straw	623^{j-m}	962^{g-l}	1351^{d-h}	1715^{b-d}	2027^{ab}
Wheat	390^{m}	575^{k-m}	896^{h-l}	1213^{e-j}	1571^{b-e}
$LSD_{0.05}$	470				
CV (%)	11.32				

Treatments with the same letter are not significantly different at $p < 0.05$; N-nitrogen fertilizer; F-fertilizer; RN-recommended nitrogen fertilizer

Table 6: Influence of precursor straw management and nitrogen fertilizer interaction under balanced fertilizeron tef biomass yield in the year of 2022

	Nitrogen fertilizer rate(kg/ha)				
Straw management	0F	0N	50% RN	75% RN	100% RN
Chickpea with straw	3074^{i-l}	3900^{g-j}	4422^{f-h}	6122^{a-c}	7263^{a}
Chickpea without straw	2415^{kl}	2478^{kl}	3315^{h-k}	4796^{d-g}	534^{c-f}
Lentil with straw	2222^{kl}	3111^{i-l}	4248^{f-i}	5685^{c-e}	7044^{ab}
Lentil without straw	2400^{kl}	2889^{i-l}	4093^{g-i}	4963^{c-g}	5914^{b-d}
Wheat	1959^{l}	2641^{kl}	3204^{i-k}	3978^{g-j}	4581^{e-g}
$LSD_{0.05}$	1197.98				
CV (%)	9.16				

Treatments with the same letter are not significantly different at $p < 0.05$; N-nitrogen fertilizer; F-fertilizer; RN-recommended nitrogen fertilizer

Similarly, during 2022 cropping season, maximum grain yield (2371 kg ha^{-1}) and biomass yield (7263 kg ha^{-1}) were obtained from application of recommended rate of nitrogen fertilizer under retaining of chickpea residue even though statistically par with plot that planted with lentil precursor and its residues and 75 percent recommended nitrogen fertilizer. The minimum values of both parameters were obtained from plot cultivated with tef without rotation and without fertilizer application.

Asfew *et al.* [34] reported that improvement in tef grain was obtained by use of fertilizer nitrogen use optimization. Similarly,Tulema *et al*. [35] indicated interaction effect of nitrogen, soil type and cultivars on N use efficiency and grain yield of tef in central high land of Ethiopia. Moreover, positive yield response of tef to nitrogen, phosphorus, potassium and sulphur under balanced fertilization were reported under Vertisols condition [36, 37]. Application of optimim rate of nitrogen fertilizer positively affected yield and yield components of cereal crop in central highlands of Ethiopia[38-40].According to Abdisa and Negessa [41], yield of cereal crop tested under balance fertilizer was significantly changed. The improvement in yield under combined use of legume precursor straw and maximum nitrogen fertilizer could be due to improvement in soil physical properties and better nitrogen response of heavy Vertisol of the area.

CONCLUSION AND RECOMMENDATIONS

The current studies showed that different precursor crop with nitrogen fertilizer rates have important impact on soil physico-chemical properties and production of tef. The effects of precursor crop with straw together with chemical nitrogen fertilizer were more prominent in the chemical properties of the soil and yield of chickpea. Soil organic matter and total nitrogen were significantly influenced by combination of precursor crops with nitrogen fertilizer while other soil chemical parameters such as (pH, av. P, K, Ca and Mg) did not significantly changed due to use of tillage methods together with mulching. Similarly, yield and yield components of tef significantly influenced by the interaction effect of precursor crop and nitrogen fertilizer g combination. Thus, maximum tef yield (2371 kg ha^{-1}) was obtained from interaction of precursor chickpea with straw and full recommended rate of nitrogen combination. It is however, important to note that in designing sustainable agricultural production by considering the characteristics of various resources like soil types, soil moisture and climatic condition of the area. Therefore, the use of precursor chickpea with straw together with and full recommended rate of nitrogen fertilizer could be the best option for both enhancing soil condition and improving tef yield under vertisol condition.

Acknowledgement: The authors are grateful to vertisol technician who supported by collecting data and analyzing soil parameters

ACKNOWLEDGMENTS

The authors are grateful to the Ethiopian Institute of Agriculture Research for the financial support and Ambo University for facilitating the budget for the research.

REFERENCES

1. Belay, G., H. Tefera, B. Tadesse, G. Metaferia, D. Jarra and T. Tadesse, 2006. Participatory variety selection in the Ethiopian cereal tef (*Eragrostis tef*). Experimental Agriculture, 42: 91-101.
2. Vandercasteelen, J., M. Dereje, B. Minten and A.S. Taffesse, 2016. Row planting teff in Ethiopia: Impact on farm-level profitability and labor allocation (Vol. 92). Intl Food Policy Res Inst.
3. Chanyalew, S., S. Ferede, T. Damte, T. Fikre, Y. Genet, W. Kebede, K. Tolossa, Z. Tadele and K. Assefa, 2019. Significance and prospects of an orphan crop tef. Planta, 250: 753-767.
4. Kidanu, S., D.G. Tanner and T. Mamo, 2000. Residual effects of nitrogen fertiliser on the yield and N composition of succeeding cereal crops and on soil chemical properties of an Ethiopian highland Vertisol. Canadian Journal of Soil Science, 80: 63-69.
5. El Wakeel, A. and A. Astatke, 1996. Intensification of agriculture on vertisols to minimize land degradation in parts of the Ethiopian highlands. Land Degradation & Development, 7: 57-67.
6. Tadele, E. and T. Hibistu, 2021. Empirical review on the use dynamics and economics of teff in Ethiopia. Agriculture & Food Security, 10: 1-13.
7. Lal, R., 1987. Managing the soils of sub-Saharan Africa. Science, 236: 1069-1076.
8. Tamene, L.D., T. Amede, J.M. Kihara, D. Tibebe and S. Schulz, 2017. A review of soil fertility management and crop response to fertilizer application in Ethiopia: towards development of site-and context-specific fertilizer recommendation. CIAT publication.
9. Zerihun, Abebe and Deressa Haile, 2017. The effect of organic and inorganic fertilizers on the yield of two contrasting soybean varieties and residual nutrient effects on a subsequent finger millet crop. Agronomy, 7: 42.
10. Altieri, M.A., C.I. Nicholls, A. Henao and M.A. Lana, 2015. Agroecology and the design of climate change-resilient farming systems. Agronomy for Sustainable Development, 35: 869-890.
11. Hall, C., T.P. Dawson, J.I. Macdiarmid, R.B. Matthews and P. Smith, 2017. The impact of population growth and climate change on food security in Africa: looking ahead to 2050. International Journal of Agricultural Sustainability, 15: 124-135.
12. Bedoussac, L., E.P. Journet, H. Hauggaard-Nielsen, C. Naudin, G. Corre-Hellou, E.S. Jensen, L. Prieur and E. Justes, 2015. Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. Agronomy for Sustainable Development, 35: 911-935.
13. Boddey, R.M., J.C.D.M. Sa, B.J. Alves and S. Urquiaga, 1997. The contribution of biological nitrogen fixation for sustainable agricultural systems in the tropics. Soil Biology and Biochemistry, 29: 787-799.
14. McLean, E.O., 1982. Soil pH and lime requirement. In "Methods of soil analysis. Chemical and microbiological properties. Part 2. Agron. series no. 9" (A. L. Page, ed.), pp: 199-234. ASA, SSSA, Madison, USA.
15. Walkley, A. and I.A. Black, 1934. An examination of method of determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science, 37: 29-38.
16. Bremner, J.M. and C.S. Mulvaney, 1982. Nitrogen total 1. Methods of soil analysis. Part 2. Chemical and microbiological properties, (methods of soil an2) pp: 595-624.

17. Bray, R.H. and L. Kurtz, 1945. Determination of total, organic and available forms of phosphorus in soils. Journal of Soil Science, 59: 39-46.
18. Murphy, J. and P. Riley, 1962. A modified single solution method for determination of phosphate in natural waters. Anal. Chem. Acta, 42: 31-36.
19. Core Team, R., 2017. R: A language and environment for statistical computing.. R foundation for statistical computing, Vienna, Austria.
20. de Mendiburu, F., 2016. agricolae: Statistical procedures for agricultural research. In "R package version, 1.2-4.
21. Lenth, R.V., 2016. Least-Squares Means: The R package lsmean. Journal of Statistical Software, 69: 1-33.
22. Crouse, D.A., 2018. Soils and Plant Nutrients, Chapter 1. In: K.A. Moore and. L.K. Bradley (eds). North Carolina Extension Gardener Handbook. NC State Extension, Raleigh, NC.
23. Tekalign, T., 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa.
24. FAO (Food and Agricultural Organization of the United State),2003. Scaling soil nutrient balances. Italy, Rome.
25. Tekalign, T., 1991. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa.
26. Cottenie, A., 1980. Soil and plant testing as a basis of fertilizer recommendations. FAO soil bulletin 38/2. Food and Agriculture Organization of the United Nations, Rome.
27. Landon, J.R., 1991. Booker Tropical Soil Manual: A hand book for soil survey and Agricultural Land Evaluation in the Tropics and Subtropics. Longman Scientific and Technical, Essex, New York. pp: 474. OR John Wiley and Sons Inc., New York.
28. Berhanu, D., 1980. The physical criteria and their rating proposed for land evaluation in the highland region of Ethiopia. Land Use Planning and Regulatory Department, Ministry of Agriculture, Addis Ababa, Ethiopia.
29. Narasimha, G., 2013. Comparative studies on physico-chemical, biological and enzymatic properties of soil amended with organic manure, vermicompost and indigenous microorganisms. BTAIJ, 7: 313-319.
30. Kp, M., T. Thomas, A.H. P and S. Rao, 2018. Effects of vermicompost and inorganic fertilizers on physico-chemical properties of soil in Indian mustard. Journal of Pharmacognosy and Phytochemistry, 7: 1999-2001.
31. Musinguzi, P., P. Ebanyat, J.S. Tenywa, T.A. Basamba and M.M. Tenywa, 2015. Precision of farmer based fertility ratings and soil organic carbon for crop production on a Ferralsol, pp: 1237-1261.
32. Negessa, G. and M. Abdisa, 2021. Integrated Soil Fertility Management Option for Enhancing Wheat Productivity in Ethiopia: Review. American-Eurasian Journal of Agronomy, 14: 29-38.
33. Negessa, G. and W. Tesfaye, 2021. Influenced of Organic and Chemical Source Fertilizer on Soil Physicochemical Properties and Nutrient Concentration of Nitisol in Welmera District, Central Ethiopia. World Journal of Agricultural Sciences, 17: 295-307.
34. Ahmed, A., N. Dechassa, S. Gebeyehu and Y. Alemayehu, 2018. Characterization of Soil of Jijiga Plain in the Somali Regional State of Ethiopia. East African Journal of Sciences, 12: 1-10.
35. Asfaw, A.G., S.A. Gedamu, H.T. Abushe, T.T. Mekonen, S.B. Muhamed and T.H. Shibeshi, 2020. Fertilizer-nitrogen use optimization for Tef in South Wollo Zone of Ethiopia. African Journal of Agricultural Research, 16: 811-818.
36. Tulema, B., F. Zapata, J. Aune and B. Sitaula, 2005. N fertilisation, soil type and cultivars effects on N use efficiency in tef [Eragrostis tef (Zucc.) Trotte]. Nutrient cycling in Agroecosystems, 71: 203-211.
37. Misskire, Y., T. Mamo, A.M. Taddesse and U. Yermiyahu, 2019. The effect of potassium on yield, nutrient uptake and efficiency of teff (*Eragrostis tef* Zucc. Trotter) on vertisols of North Western Ethiopian Highlands. Journal of Plant Nutrition, 42: 307-322.
38. Chala, G., S. Kassa, T. Tadele, K. Assefa, H. Teshome, G. Agegnehu, W. Abera, D. Tibebe, G.W. Sileshi and T. Erkossa, 2022. Yield response of tef (*Eragrostis tef*) to nitrogen, phosphorus, potassium and sulphur under balanced fertilization on Vertisols in different agroecological zones of Ethiopia. Experimental Agriculture, 58: 12.
39. Negessa, G. and M. Abdisa, 2023. Integrated Use of Fertilizer Source Increase Yield and Economic Benefits of Wheat. International Journal of Sustainable Agriculture, 11: 01-08.
40. Negessa, G., 2021. Vertisol Management for Improving Wheat and Teff Production in Ethiopia: Review. World Journal of Agricultural Sciences, 17: 62-69.
41. Abdisa Mekonnen and Negessa Gadisa, 2021. Effect of NPS Fertilizer Rates on Uptake and Use Efficiency of Food Barley (*Hordeum vulgare* L.) Varieties at Welmera District, Central Highlands of Ethiopia. World Journal of Agricultural Sciences, 17: 268-277.