EFFICACY OF VERMICOMPOST AND UREA ON FORAGE GRASS GROWTH, YIELD, AND SOIL PROPERTIES IN ETHIOPIA †

[EFICACIA DE LA VERMICOMPOSTA Y LA UREA EN EL CRECIMIENTO Y RENDIMIENTO DE PASTO FORRAJERO Y PROPIEDADES DEL SUELO EN ETIOPÍA]

Enyew Mekcha[1,2*], Bimrew Asmare[1], Netsanet Beyero[1], and Shigdaf Mekuriaw[3]

[1]Department of Animal Science, College of Agriculture and Environmental Science, Bahir Dar University, P.O. Box 5501, Bahir Dar, Ethiopia. Email: limsam2009@gmail.com and chubeyero@gmail.com
*[2] Department of Animal Science, College of Agriculture, Food and Climate Science, Injibara University, P.O. Box 40, Injibara, Ethiopia. Email: eniyewu@gmail.com **
[3] International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia. Email: shigdaf@gmail.com
** Corresponding author*

SUMMARY

Background: Utilizing improved forage grasses such as Napier (*Pennisetum purpureum, acc. 15743)*, Desho (*Pennisetum glaucifolium)*, and Gunia (*Panicum maximum)* grasses with proper management practices has the potential to solve the feed scarcity challenges in Ethiopia. **Objective**: To evaluate the effect of vermicompost (VC) and urea on the morphological characteristics and dry matter yield (DMY) of Napier, Desho, and Gunia grasses, as well as soil chemical properties across different altitudes of northwestern Ethiopia. **Methodology:** The experiments were conducted at mid and high-altitude locations using a Randomized Complete Block Design (RCBD) with a factorial arrangement and three replications. The treatments used were control (no fertilizer), 100% Vermicompost, 100% urea, 30% urea + 70% vermicompost, and 70% urea VC +30% vermicompost. Morphological parameters like plant height (PH), number of tillers per plant (NTPP), number of leaves per plant (NLPP), and Leaf length per plant (LLPP) were measured. The DMY t ha^{-1} and leaf-to-stem ratio (LSR) were also measured. Soil chemical properties were analyzed before and after forage cultivation, and the composition of vermicompost was also analyzed. **Results:** Results showed that fertilizer treatments positively influenced the morphological parameters, DMY t ha^{-1}, and soil chemical properties compared to the control treatment. Combined application of urea and vermicompost generally performed better than individual application, however, the difference among the combined treatments was not statistically significant. Better performance of forage grass was observed at the mid-altitude compared to the high altitude, with Napier grass showing the highest DMY t ha^{-1}. **Implications:** The findings highlight the importance of altitude, forage grass species, and fertilizer application in enhancing soil chemical properties and productivity of forage grasses in Ethiopian farming systems. The combined use of vermicompost and urea shows promising potential and could be prioritized to optimize forage grass production. **Conclusion:** The application of vermicompost, urea, and their combination significantly improves the morphological parameters, DMY t ha^{-1}, and soil chemical properties compared to the control treatment. To sustainably improve the productivity of livestock feed resources in Ethiopia, integrating improved forage varieties with enhanced agronomic management practices, particularly proper fertilizer application, is strongly recommended.
Key words: Fertilizer treatment; Dry matter yield; Forage grass; Vermicompost – Urea integration; Soil Fertility

RESUMEN

Antecedentes: El uso de pastos forrajeros mejorados como el pasto Napier (*Pennisetum purpureum*, acc. 15743), el pasto Desho (*Pennisetum glaucifolium*) y el pasto Gunia (*Panicum maximum*) con prácticas de manejo adecuadas tiene el potencial de resolver los desafíos de escasez de alimento en Etiopía. **Objetivo**: Evaluar el efecto de la vermicomposta (VC) y la urea en las características morfológicas y el rendimiento de materia seca (DMY) de los pastos Napier, Desho y Gunia, así como en las propiedades químicas del suelo en diferentes altitudes del noroeste de Etiopía. **Metodología**: Los experimentos se llevaron a cabo en localidades de altitud media y alta utilizando un diseño de bloques completos aleatorizados (RCBD) con un arreglo factorial y tres réplicas. Los tratamientos utilizados fueron control (sin

† *Submitted February 28, 2025 – Accepted May 30, 2025.* http://doi.org/10.56369/tsaes.6220

ISSN: 1870-0462.
ORCID = **E. Mekcha**: http://orcid.org/0000-0001-8204-5920; **B. Asmare**: http://orcid.org/0000-0002-5065-6476; **N. Beyero**: http://orcid.org/0000-0002-2005-0449; **S. Mekuriaw**: http://orcid.org/0000-0002-3519-6061

fertilizante), 100% Vermicomposta, 100% urea, 30% urea + 70% vermicomposta y 70% urea VC + 30% vermicomposta. Se midieron parámetros morfológicos como la altura de la planta (AP), el número de macollos por planta (NMP), el número de hojas por planta (NPP) y la longitud de la hoja por planta (NPP). También se midieron las t DMY ha^{-1} y la relación hoja-tallo (LSR). Se analizaron las propiedades químicas del suelo antes y después del cultivo de forrajes, y también se analizó la composición de la vermicomposta. **Resultados**: Los resultados mostraron que los tratamientos con fertilizantes influyeron positivamente en los parámetros morfológicos, las t DMY ha−1 y las propiedades químicas del suelo en comparación con el tratamiento control. La aplicación combinada de urea y vermicomposta generalmente tuvo un mejor rendimiento que la aplicación individual; sin embargo, la diferencia entre los tratamientos combinados no fue estadísticamente significativa. Se observó un mejor rendimiento de las gramíneas forrajeras en la altitud media en comparación con la altitud alta, siendo el pasto Napier el que mostró las t DMY ha^{-1} más altas. **Implicaciones**: Los hallazgos resaltan la importancia de la altitud, las especies de gramíneas forrajeras y la aplicación de fertilizantes para mejorar las propiedades químicas del suelo y la productividad de las gramíneas forrajeras en los sistemas agrícolas etíopes. El uso combinado de vermicomposta y urea muestra un potencial prometedor y podría priorizarse para optimizar la producción de pastos forrajeros. **Conclusión**: La aplicación de vermicomposta, urea y su combinación mejora significativamente los parámetros morfológicos, las t de RMS ha^{-1} y las propiedades químicas del suelo en comparación con el tratamiento control. Para mejorar de forma sostenible la productividad de los recursos forrajeros en Etiopía, se recomienda integrar variedades mejoradas de forrajes con prácticas de gestión agronómica optimizadas, en particular la aplicación adecuada de fertilizantes.
Palabras clave: Tratamiento de fertilizantes; Rendimiento de materia seca; Pasto forrajero; Integración de vermicompost y urea; Fertilidad del suelo.

INTRODUCTION

Feed insecurity is the primary challenge to the sustainability of livestock production in Ethiopia (Mengistu *et al*, 2017, Tolera *et al.*, 2019; Bezabih *et al*., 2020; Balehegn *et al*., 2020). Currently, feed insecurity is being aggravated because of the increase in livestock populations, urbanization, infrastructure development, and the expansion of cropland, which is leading to a reduction in grazing Shapiro *et al*.(2020), which indirectly reduces livestock productivity (Berhe *et al*., 2024). Shapiro *et al*. (2020), forecast a shortage of approximately 1.332 million tons of meat and 1.987 million liters of milk by 2028 due to increased demand for animal products, while productivity is decreased. The population of livestock is projected/expected to rise approximately from 65 million CSA (2021) to over 90 million by 2030; thus, livestock feed insecurity will also increase.

To address these growing feed challenges and ensure sustainable livestock productivity in Ethiopia, one promising approach involves the effective use of adopted and improved forage grass species with better agronomic practices such as proper harvesting and fertilizer application (Abera *et al*., 2021; Alemie and Gebremedhin, 2019). Desho, Napier, and Gunia grasses are some of the most widely used improved forage grasses used for livestock feed. They are adapted to the different agro-ecologies, making them suitable across Ethiopia (Feyissa *et al*., 2022). These improved forage grass species provide a sustainable solution that enhances the productivity of the livestock Mengistu *et al.* (2017) and Shifa *et al.*(2024), by reducing the dependency of animals on natural pasture, high biomass production per unit area (Getaneh, 2021) and also mitigating greenhouse gas emissions (Paul *et al*., 2020). Besides livestock feed, these forage grasses are used for soil and water conservation activities (Beyene *et al.*, 2022; Ayele *et al*., 2021; Notenbaert *et al*., 2021). Therefore, using these improved forage grasses is a promising alternative to reduce the impacts of feed-related crises.

Limited soil fertility, however, delayed the production potential of those improved forage grasses in Ethiopian conditions (Tessema *et al.*, 2011). This soil infertility contributes to low biomass production and poor forage quality, aggravating feed shortages in smallholder farming systems. In such cases, applying fertilizers is pivotal in restoring soil fertility and unlocking the yield potential of improved forage cultivated in Ethiopia. Inorganic fertilizers like urea and DAP (Diammonium Phosphate) have been applied to the soil to enhance soil fertility, increase biomass yield, and improve the nutritional profile of forage grass (Bedaso *et al*., 2022). Nevertheless, the dependency on inorganic fertilizer poses challenges, including negative impacts on soil health, low affordability by smallholder farmers, high costs, and competition with food. These drawbacks of inorganic fertilizers underscore the growing interest in organic fertilizers like vermicompost, which is environmentally friendly, highly affordable, and cost-effective (Yadav *et al*., 2021).

Vermicompost (VC) is an organic fertilizer produced through the breakdown of organic materials using earthworms (*Eisenia fetida, spp*) and microorganisms Edwards *et al. (*2010), which produces a stable, peat-like material with a low carbon to nitrogen (C: N) ratio. Moreover, it is a sustainable alternative and an ecofriendly technology that results in valuable organic-rich humus under aerobic conditions (Aslam and Ahmad, 2020). On the other hand, vermicomposting is considered a sustainable approach to waste management and agricultural production, and it plays a pivotal role in mitigating greenhouse gas emissions (Panda *et al*., 2022). The application of vermicompost significantly improves the overall physical and biochemical properties of soil, while also reducing exchangeable acidity (Terefe *et al*., 2024a). This, in turn, enhances the availability of plant nutrients in acidic soils, leading to sustainable crop production (Dubey *et al*., 2020). In addition, using vermicompost alone or in combination with other fertilizers enhances the yield, growth, shoot biomass, root volume, and plant height, which promotes sustainable crop production (Adhikary, 2012; Andrade, 2013; Sabrina, 2013; Joshi *et al*, 2013).

However, the individual application of vermicompost to forage grass cannot achieve sustainable forage production Aslam *et al.* (2024) because of nutrient imbalance in vermicompost (Markam., 2021). Therefore, there is a need to find the midpoint between synthetic fertilizer (urea) and organic fertilizer (vermicompost) that may sustain forage production without affecting soil health and the environment. Given the individual limitations of both inorganic and organic fertilizers, the combined application of vermicompost and urea can address soil nutrient deficiencies, mitigate soil quality deterioration, and improve forage productivity (Oyege and Bhaskar, 2023; Singh and Misal, 2022).

Ethiopia has diverse agroecological zones such as lowland, midland, and highland, each with varying climatic conditions such as temperature, rainfall, and soil conditions, which significantly influence forage growth, nutrient uptake, and biomass production (Fikadu *et al.,* 2022). Understanding site-specific responses to fertilizer application is therefore crucial for optimizing forage productivity. Therefore, the current study aimed to evaluate the effect of vermicompost and urea on the morphological characteristics and dry matter yield of Napier, Desho, and Gunia grasses, besides soil chemical properties across different altitudes of Ethiopia.

MATERIALS AND METHODS

Description of study areas

The field experiment was conducted simultaneously during the main cropping season in the North Mecha (Ambomesk kebele) and Banja districts (Injibara University) to represent the mid and high altitudes, respectively, in northwestern Ethiopia. North Mecha district is located 35 km from Bahir Dar and 520 km from Addis Ababa, the capital of the Amhara region and Ethiopia, respectively (Figure 1). Geographically, North Mecha district lies between 11°5′N 11°38′ latitude and 36°58′ 37°22′E longitude and at an elevation of 1800-2500 masl. The mean annual rainfall and district temperature are around 3043.9mm and 23.5°C, respectively. The major soil type of the district is Nitisol, characterized by low pH and high exchangeable acidity (Terefe et al., 2024a). Farmers widely apply inorganic fertilizers like urea and Nitrogen-Phosphorus-Sulfur blend fertilizer (NPS) to increase crop yield (Terefe *et al.*, 2024a). Furthermore, furrow irrigation is a common irrigation practice in the district

Banja district is located at a distance of 440 km in northwestern Addis Ababa and 120 km southeast of Bahir Dar, the capital of Ethiopia. Geographically, the district is located at a latitude of 10^0 56'' 17'' N, and longitude of 36^0 52'' 16'' E, and an altitude of 2509 meters above sea level. According to the National Meteorological Service Agency from 1984 to 2017, the mean minimum and maximum temperatures of the study area were 10.3^0 C and 22.5^0 C, respectively and the mean annual rainfall was 1344 mm, with the main wet season lasting from June to September, followed by a less pronounced wet period until November.

Land preparation and experimental materials

The experimental sites were cleared, plowed by a tractor, and harrowed again using oxen 20 to 30 days before plot layout and planting to facilitate soil aeration and remove unwanted weeds. The required number of grasses for the experiment, characterized by good vigor, strength, and freedom from injury, was taken from the Andassa livestock research center. Vermicompost prepared from cattle manure, green material, crop residues, and straw was purchased from the Banja district farmers' training center, and urea was purchased from the local market (Merawi and Injibara town). Vermicompost was prepared in the Banja farmers' training center for 2 months from February to April 2023 as per the recommendation of Jaganathan *et al.* (2013) using wood-made boxes. 1 m^2 boxes were used for vermicompost preparation. Bedding materials were brought to the area and equally distributed filling each bedding box. Cow dung and leafy materials were mixed and kept for five days for partial decomposition. *Eisenia fetida* species was used for vermicompost preparation, and approximately two hundred individual species were stocked in each of the bedding boxes.

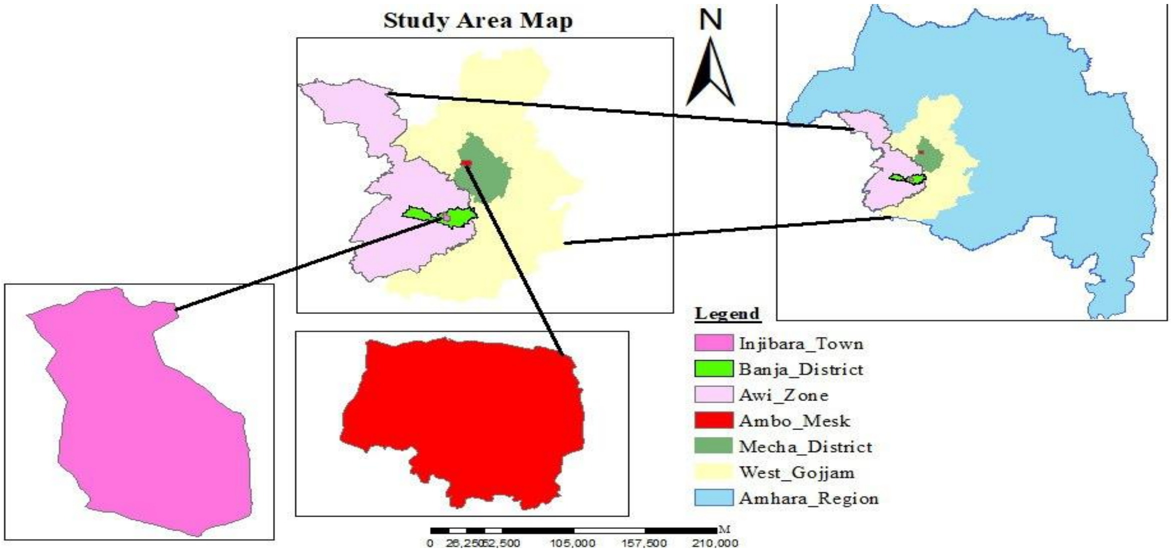

Figure 1. Location Map of the Study Area in Northwestern Ethiopia, Amhara Region

The composting boxes were checked daily to ensure optimal conditions for worm culture. Key physicochemical parameters, including moisture, aeration, temperature, and pH, were carefully checked and maintained throughout the process. To sustain the ideal moisture level, water was sprayed daily onto the vermicompost, and plastic sheets were placed over each bedding box to prevent moisture loss. Harvesting took place on the 60^{th} day, at which point the worms were separated from the vermicast. The young worms and cocoons were separated from the vermicompost by hand as soon as the harvest, and using 3 mm sieves after the moisture was removed. The average C: N ratio of vermicompost used in the current study was 6.82: 1 (Table 1). Finally, the required amount of vermicompost and urea was applied based on the recommendation of Joshi *et al*.(2013) and Diriba *et al. (*2013), respectively. Based on the recommendation, 5 t ha^{-1} Vermicompost and 100 kg ha^{-1} urea were used for the current study. Vermicompost was applied 35 days before, while urea was applied after forage establishment. Before uprooting the seedlings of grasses, the leaves were removed to reduce wilting by more water loss through transpiration.

Soil sample and vermicompost analysis

In both districts, soil samples were collected in May before planting experimental forage grass cultivars at a depth of 30 cm by the vertical insertion of a shovel and mixed to get a composite sample. Plant litter and other dirty materials on the soil surface were removed before collecting the samples. Soil sample collection followed the diagonal (X) sampling method, and composite samples of soils in both districts were made and put into a sterile plastic bag. The soil samples were mixed, taken as one composite sample, and brought to the Injibara University laboratory. Furthermore, at the end of the experiment, soil samples were collected from each plot, and composite samples per treatment were used for further analysis. The samples were air-dried in an open space and then crushed with a mortar and pestle to make them fine and easy to grind with a mill. All chemical soil analysis was estimated following standard methods as described by Okalebo *et al*. (2002). Similar patterns were followed for the chemical analysis of vermicompost. The experimental land was cleared, plowed by tractor, and harrowed again by oxen plowing on days 20 to 30 before laying out plots and planting, to facilitate soil aeration and to remove unwanted weeds.

Chemical composition of soil in the mid and high-altitude locations before planting

The chemical composition of the soil before planting and VC used is presented in Table 1. According to the classification of (Landon, 2015), the pH level of the soil recorded from the mid-altitude (5.31) is moderately acidic, while the pH level of the soil recorded in the high altitude (5.04) is strongly acidic. The Organic carbon (OC) obtained in the current study was low both in the mid (3.19) and high-altitude (2.81) locations, as per the rating by (Landon, 2015) Those who classified soil having above 20%, 10-20, 4-10, 2-4, and below 2 are very high, high, medium, low, and very low, respectively. The total nitrogen (TN) of the soil in both altitudes was also low based on the classification of Landon 2014, who classified soils having TN 0.1-0.2 as low TN soils. On the other hand, the available phosphorus in the soil, both in the mid and high altitudes, is rated as very low. Based on the same classification, the CEC composition of soil in the mid-altitude (28.64) is grouped as high, while the Cation Exchange Capacity (CEC) in the high-altitude (24.9) location is rated as medium. The available phosphorus of the soil (AvP) and the organic matter (OM) content of the soil were higher in the mid-altitude than in the high-altitude location. Compared to the composition of the soil before the addition of fertilizer, VC had relatively high pH, OC, TN, AvP, OM, and CEC (Table 1).

Table 1. Chemical composition of the soil before application of fertilizer and vermicompost.

Soil properties	Experimental site		Vermicompost
	Mid-land	High-land	
pH	5.31	5.04	7.52
OC (g kg^{-1})	3.19	2.81	12.41
TN (g kg^{-1})	0.19	0.18	1.82
AvP (ppm)	2.74	1.96	5.03
OM (g kg^{-1})	2.41	2.12	18.52
CEC (cmol kg^{-1})	28.64	24.9	65.25

OM = Organic matter, TN = Total Nitrogen, AvP =Available Phosphors, CEC = Cation Exchange Capacity, OC = Organic Carbon, g kg^{-1} = gram per kilogram, cmol kg^{-1} = centimole per kilogram; ppm = part per million

Treatments and experimental design

The experiment was conducted with a randomized complete block design (RCBD), in a factorial arrangement (three forage grasses by five fertilizer levels) and three replications in both mid and high-altitude research sites. The experiment comprised 45 plots at each altitude. Each experimental unit had an area of 3m*3m with 1m and 0.5m between blocks and plots, respectively. Inter-row and intra-plant spacing were 0.5m and 0.3m, respectively, comprising 60 plants in each plot. The three forage grasses, namely Desho grass *(Pennisetum glaucifolium*, Kulumsa DZF-592), Napier grass (*Pennisetum purpureum acc. 15743),* and Gunia (*Panicum maximum*) grasses, were collected from the Andassa livestock research center. The forage grasses were selected based on yield, adaptability, and good nutritional composition compared to other forage grasses. The treatment combination for each grass is presented in Table 2.

Table 2. Treatment Combination.

Treatments	Level of application
T1	Forage grass + no fertilizer
T2	Forage grass + 100%VC
T3	Forage grass + 70%VC:30%U
T4	Forage grass + 30%VC:70%U
T5	Forage grass + 100%U

VC = vermicompost, U = Urea

Data collection

Plant growth variables such as plant height (PH), number of tillers per plant (NTPP), number of leaves per plant (NLPP), leaf length per plant (LLPP), and leaf width per plant (LWPP) were determined from an average of eight randomly selected plants from the middle rows of each plot. Plant height was determined by measuring the height of the main shoot of each sample plant from its base to its last leaf. The number of tillers per plant, the number of leaves per plant, and the number of roots per plant were determined by counting them visually in each of the eight sample plants from each plot, respectively. The leaf length of each sample plant was determined by measuring the size of each leaf from the base to the tip of the leaf, and the mean was calculated for each sample plant. The number of nodes per plant was also counted from the sample plants. Harvesting was done by hand using a sickle, leaving a stubble height of roughly 8 cm above the ground, Lounglawan *et al.* (2014) at 105 days of age. Leaf area was calculated by multiplying leaf length by the average leaf width measured at the bottom, mid, and tip of the leaf. The leaf-to-stem ratio was determined by dividing the leaf dry weight by the stem dry weight of the sample plants from each plot. For each of these growth variables, the mean of the sample plants was calculated and used for statistical analysis.

Dry matter yield measurement

After individual plant measurements, the stem and leaves were bulked separately, and about 500g of stem and leaves were taken for dry matter analysis. When the grass reached the proper harvesting date, the sample grass was harvested from the two middle rows of each plot (1m^2) at 8cm above the ground. Soon after harvesting from 1m^2, the fresh weight was measured, and afterward, 500 grams of fresh weight of each grass sample was air dried. After determining the dry matter, the dry matter yield of each forage grass per 1m^2 was computed by multiplying the dry matter percentage with the fresh biomass taken from the sampling area and converting the result to t ha^{-1}.

Statistical Analysis

The collected data were subjected to the analysis of variance (ANOVA) using the GLM procedure of R Studio version 4.3.2. The difference among means was separated by Tukey's honest significant test when treatment effects were significant ($P< 0.05$). The statistical model for this design was:

$$Yijk = \mu + Bi + Fj + Ak + Al + (Fj * Ak*Al) + eijkl.$$

Where:

Yijk =the response (dependent) variables, μ = overall mean, Bi= i[th] block effect, Fj = j[th] factor effect (fertilizer treatment), Ak = k[th] factors effect (forage grasses), Al = altitude effect, Fj*Ak*Al= interaction effect (fertilizer level * forage grasses, fertilizer level*altitude, forage grass*altitude), eijkl = random error

RESULTS

Post-harvest soil Chemical composition

Table 3 presents the interaction effect of altitudes, fertilizer level, and forage grasses on soil chemical properties. The chemical composition of the soil was improved after the application of fertilizer (VC and urea). The current finding elucidates that the composition of soil pH, OC, TN, OM, CEC, and AvP content was significantly ($P<0.001$) higher for each fertilized plot than for unfertilized plots. The soil pH, OC, TN, OM, CEC, and AvP contents were significantly ($p<0.001$) highest for the full dose (100%) of VC, but were lower for the sole application of urea. Improvements in soil composition were observed as the VC level increased. The full dose application of urea (100%) had a lower improvement in soil chemical composition than the full dose (100%) application of VC, but improvement was observed over the control plot.

Significantly ($P<0.001$) higher pH level of soil was found in the mid-altitude location (6.06) compared to the high-altitude location (5.66) (Table 3). Other soil parameters, such as percentage of organic carbon (%OC), total nitrogen (TN), organic matter (OM), cation exchange capacity (CEC), and available phosphorus (AvP), were also significantly ($P<0.001$) higher in the mid-altitude compared to the high-altitude location.

Table 3. Interaction effect of fertilizer type, forage grasses, and altitude on soil composition after forage harvest.

Variables	Parameters					
	pH	OC (g kg^{-1})	TN (g kg^{-1})	AvP (ppm)	OM (g kg^{-1})	CEC (cmol kg^{-1})
Altitude						
Mid	6.06^{a}	4.08^{a}	0.27^{a}	3.17^{a}	3.20^{a}	32.80^{a}
High	5.66^{b}	3.69^{b}	0.23^{b}	2.21^{b}	2.79^{b}	27.48^{b}
Sig	***	***	***	***	***	***
Forage grass						
Desho grass	5.86	3.90a	0.26^{a}	2.66^{b}	2.97	30.28^{a}
Napier grass	5.85	3.89a	0.24^{b}	2.69^{a}	3.03	30.16^{ab}
Panicum *maximum* grass	5.87	3.84b	0.26^{a}	2.71^{a}	3.00	29.98^{b}
Sig	**ns**	**	***	***	**ns**	*
Fertilizer treatments						
Control	5.28^{e}	3.01^{e}	0.19^{d}	2.38^{d}	2.26^{d}	26.44^{d}
100%VC	6.34a	4.62^{a}	0.32^{a}	2.93^{a}	3.57^{a}	33.18^{a}
70%VC:30% Urea	6.19^{b}	4.48^{b}	0.29^{b}	2.91^{a}	3.49^{a}	33.32^{a}
30% VC: 70% Urea	5.89^{c}	3.90^{c}	0.25^{c}	2.69^{b}	3.20^{b}	29.86^{b}
100% Urea	5.59^{d}	3.39^{d}	0.20^{d}	2.54^{c}	2.47^{c}	27.89^{c}
Overall mean	5.86	3.88	0.25	2.69	3.00	30.14
Sig	***	***	***	***	***	***
CV (%)	0.65	1.38	9.08	1.51	3.60	1.53
SE	0.02	0.03	0.013	0.02	0.06	0.27
Interaction						
Fg*Ft	***	***	*	***	***	***
Fg*Alt	***	***	Ns	***	***	***
Alt*Ft	***	***	***	***	***	***
Alt*Fg*Ft	***	***	Ns	***	***	***

*=significant at 0.05, **=significant at 0.01, ***=significant at 0. 001, means within a row followed by the same letters are not significantly different, ns = not significant, SE = Standard error, %OC = percent organic matter, TN = Total nitrogen, AvP = Available phosphorus, %OM = Percent organic matter, CEC = cation exchange capacity, g kg^{-1} = gram per kilogram, cmol kg^{-1} = centimole per kilogram, ppm = part per million

Although no significant difference was observed, planting of Guinea grass improves the pH level of the soil, followed by Desho and Napier grass. Planting Desho and Guinea grass improves the soil TN compared to the cultivation of Napier grass. On the other hand, the cultivation of Napier and Guinea grass improves the AvP over the planting of Desho grass. No significant differences in the CEC value of the soil were recorded among the forage grasses cultivated in the current study.

The interaction effects among forage grasses, fertilizer types, and altitude significantly affected the chemical properties of soil (Table 3). Specifically, soil pH was significantly affected by the interactions between forage grass and fertilizer, forage grass and altitude, as well as altitude and fertilizer. Similarly, other soil properties, including organic carbon (OC), available phosphorus (AvP), organic matter (OM), and cation exchange capacity (CEC), were significantly ($P< 0.001$) influenced by these same interaction effects. However, the interaction between altitude and forage grass did not have a significant effect on the total nitrogen (TN) content of the soil.

Plant growth characteristics and dry matter yield (t ha^{-1}) **of forage grass**

The effects of fertilizer, forage grass, altitudes, and their interaction on the morphological characteristics and dry matter yield (t ha^{-1}) of forage grasses are presented in Table 4. Forage grasses in the mid-altitude are significantly ($P<0.001$) taller (118.91cm) than forage grasses in the high-altitude location (101.84cm). Similarly, the NTPP (33.54), LLPP (56.24cm), NLPP (233.37), NRPP (112.56), and RLPP (38.54cm) in the mid-altitude location were significantly ($P<0.001$) higher than NTPP (28.1), LLPP (43.66cm), NLPP (207.94), NRPP (93.46), and RLPP (29.02cm) in the high-altitude location (Table 4). The Dry matter yield (t ha^{-1}) of forage grass was also significantly higher in the mid-altitude (3.59 t ha^{-1}) than high altitude (3.06 t ha^{-1}) location. Higher LSR of forage grass in the current study was recorded from the mid-altitude (1.7) location than the high altitude (1.53).

Plant height (PH) was significantly affected by the addition of different levels of VC and urea. The tallest plant was recorded from the grass amended with 70% VC + 30 % Urea (121.44cm) and 30% VC +70 % Urea (119.83cm) than the other treatment combinations (Table 4). The shortest PH of forage grasses was recorded from the control plots (96.88cm) than the other fertilizer treatments. Compared to the sole (100%) application of VC (102.2cm), longer PH was recorded from the full dose application of urea (111.52cm). The other morphological parameters, such as NTPP, NLPP, LWPP, and NRPP, were higher in the combined application than in the sole application of each fertilizer, and improvement was observed as the level of VC increased. The lowest morphological parameters, like PH (96.88cm), NTPP (25), LLPP (43.65cm), NLPP (208.67), NRPP (91.92), and RLPP (29.11cm) were recorded from the control treatment. Compared to the sole (100%) application of VC, the improved morphological parameters were recorded from the full dose (100%) application of urea. The improved morphological parameters were recorded from the combined application rather than the sole application of each fertilizer. Similar to other morphological parameters, higher LSR and DMY (t ha^{-1}) of forage grass were obtained from the fertilized treatment than from the unfertilized plot. The combined application also improves the LSR and DMY (t ha^{-1}) of forage grass than the single application.

The longest plant was recorded from Napier grass (142.78cm) and was significantly ($P<0.001$) higher compared to Guinea (119.41cm), and Desho grass (68.93cm). The NTPP was significantly ($P<0.001$) higher for Desho grass (53.92) followed by Napier (21.04), while fewer NTPP were recorded from Guinea grass (17.50) (Table 4). Similarly, the highest number of roots (124.89) was recorded from Desho grass than from Guinea (106.23) and Napier grass (77.91), respectively (Table 4). The root length (58.23cm) and leaf length (71.19cm) were higher for Napier grass than for Guinea and Desho grass. A smaller number of tillers (17.5) and roots (77.91) were recorded from Guinea grass and Napier grass, respectively. Significantly ($P<0.001$) higher DMY (t ha^{-1}) of forage grass was obtained from Napier grass (4.44 t ha^{-1}) followed by Guinea (3.29 t ha^{-1}) and Desho grass (2.24 t ha^{-1}), respectively. The LSR of forage grass was higher for Napier grasses (2.55), and the lowest LSR was obtained from Guinea grass (1.05).

Except for soil pH, the interaction between forage grass and fertilizer treatment significantly affected the morphological parameters and dry matter yield (DMY) of the forage grasses. Likewise, the interaction between forage grass and altitude had a highly significant effect ($P<0.001$) on these same parameters. In contrast, the interaction between altitude and fertilizer treatment had no significant effect on the number of NTPP, LWPP, PH, and LSR. However, it significantly influenced the LLPP, NLPP, NRPP, LA, and DMY of the forage grasses.

Table 4. Interaction effect of fertilizer levels, altitudes, and forage grass on the morphological characteristics and dry matter yield (t ha^{-1}) of forage grasses.

Variables	Parameters									
	NTPP (count)	LLPP (cm)	LWPP (cm)	NLPP (count)	PH (cm)	NRPP (count)	RLPP (cm)	LA	LSR	DMY (t ha^{-1})
Altitudes										
Mid	33.54^{a}	56.24^{a}	2.08^{a}	233.37^{a}	118.91^{a}	112.56^{a}	38.54^{a}	121.7^{a}	1.70^{a}	3.59^{a}
High	28.10^{b}	43.66^{b}	1.82^{b}	207.94^{b}	101.84^{b}	93.46^{b}	29.02^{b}	83.97^{b}	1.53^{b}	3.06^{b}
Sig	***	***	***	***	***	***	***	***	***	***
Forage grass										
Desho grass	53.92^{a}	26.21^{c}	1.56^{c}	310.59^{a}	68.93^{c}	124.89^{a}	8.49^{c}	41.55^{c}	1.25^{b}	2.24^{c}
Panicum grass	17.5^{b}	52.45^{b}	2.26^{a}	233.79^{b}	119.41^{b}	106.23^{b}	34.62^{b}	120.85^{b}	1.05^{c}	3.29^{b}
Napier grass	21.04^{b}	71.19^{a}	2.03^{b}	117.58^{c}	142.78^{a}	77.91^{c}	58.23^{a}	146.10^{a}	2.55^{a}	4.44^{a}
Sig	***	***	***	***	***	***	***	***	***	***
Fertilizer treatments										
Control	25.00^{d}	43.65^{d}	1.71^{d}	208.67^{d}	96.88^{d}	91.92^{d}	29.11^{d}	77.57^{d}	1.43^{d}	2.65^{d}
100%VC	27.62^{c}	47.42^{c}	1.83^{c}	215.08^{c}	102.20^{c}	97.62^{c}	31.47^{c}	90.53^{c}	1.51^{c}	2.90^{c}
70%VC:30%U	35.83^{a}	54.65^{a}	2.16^{a}	229.07^{a}	121.44^{a}	111.10^{a}	37.89^{a}	123.85^{a}	1.76^{a}	3.93^{a}
30% VC: 70% U	35.49^{a}	53.74^{a}	2.11^{a}	229.54^{a}	119.83^{a}	110.03^{a}	37.22^{a}	118.76^{a}	1.74^{a}	3.86^{a}
100%U	30.15^{b}	50.28^{b}	1.96^{b}	220.93^{b}	111.52^{b}	104.38^{b}	33.22^{b}	103.45^{b}	1.64^{b}	3.29^{b}
Sig	***	***	***	***	***	***	***	***	***	***
Overall mean	30.82	49.95	1.95	220.66	110.37	103.01	33.78	102.83	1.62	3.33
CV (%)	5.02	2.51	4.27	1.31	2.75	1.95	3.44	5.79	3.26	2.81
SE	0.894	0.73	0.15	1.63	1.77	1.169	0.683	3.47	0.028	0.05
Interaction										
Fg*Ft	***	***	***	***	ns	***	***	***	**	***
Fg*Alt	***	***	***	***	***	***	***	***	*	***
Alt*Ft	Ns	*	Ns	***	Ns	**	Ns	**	Ns	***

*=significant at 0.05, **=significant at 0.01, ***=significant at 0. 001, means within a row followed by the same letters are not significantly different, ns = not significant, SE = Standard error, NTPP = number of tillers per plant, LLPP = leaf length per plant, LWPP = leaf width per plant = NLPP = number of leaves per plant, PH = plant height, NRPP = number of roots per plant, RLPP = root length per plant = LA, leaf area, LSR = leaf to stem ratio, and DMY = Dry matter yield, U = urea

DISCUSSION

Post-harvest soil chemical properties

The result of the current study showed that soil chemical properties were altered after the application of different levels of VC and urea fertilizer. The full dose (100%) addition of VC to the soil increased soil pH level by 20.08% and 13.42% compared to the unfertilized treatment and 100% urea application, respectively. The increment of soil pH in the sole addition of VC was supported by the research (Terefe *et al.,* 2024). The significant increase in soil pH in the full dose (100%) VC addition might be attributed to the reduction of soil acidity through the decomposition of organic matter (OM) (Assefa, 2019) and the addition of basic cations from VC to the soil (Alem and Fassil, 2015) which can help buffer the soil against a decrease in pH**.**

Moreover, the current study found that the combined application of VC with urea significantly improved the pH level of the soil compared to the application of urea alone (100%). In line with this finding, Habtamu *et al.* (2024), Lemmesa. (2020); Terefe *et al*. (2024b) have reported that the combined application of organic and inorganic fertilizers improves the pH level of the soil in the Ethiopian farming system. In contrast, the lowest pH level of the soil was observed in the 100% urea-amended treatments, likely due to could be due to the acidifying effect of urea, which releases H^{+} ions during nitrification and plant root uptake (Desta, 2015). A lower pH level of soil was obtained from the control treatment, possibly due to the absence of more decayed material of forage grass, due to the lower performance of forage grass in the control plots.

The full dose (100%) addition of VC also increased the nitrogen content of the soil by 60% more than compared to the sole urea application, which might be attributed to, the nitrogen found in inorganic fertilizer (urea) decomposes quickly which could easily leach, while N found in the organic fertilizer (VC) is released more slowly remain available in the soil until the end of the forage harvest (Richter and Roelcke, 2000). Similarly, Ghimire *et al.* (2023) and Habtamu *et al*. (2024) found and proved that the application of VC improves the nitrogen content of the soil. In contrast to the current study, Gadisa. (2021), applying inorganic fertilizer together with organic fertilizer increased the total N content of the soil than when used separately. In the current study, the combined application of VC and urea increases the TN contents of the soil over the control treatment, which is consistent with the finding of Habtamu *et al.* (2024).

The result of the current study further revealed a significant difference in available phosphorus (AvP) among the examined treatments. The highest AvP was obtained from the 100% VC-treated plot, while the lowest was from the control treatments. The increased AvP could be attributed to OM in the VC enhancing phosphorus mineralization and availability in the soil (Terefe *et al*., 2024b). In line with this, Habtamu *et al*. (2024) reported that the combined application of VC and inorganic fertilizer resulted in an increment in the AvP of the soil after crop harvest, as compared to the control treatment. Terefe *et al.*(2024b) also found that the addition of VC and mineral fertilizer to the soil enhances the phosphorus content of the soil after crop harvest.

The current study revealed that the CEC value of the soil significantly varies across treatments. The highest CEC value of the soil was recorded in the 70% VC:30% Urea treatment, while the lowest was recorded from the control treatment (Table 4). The increase in the CEC value of soil in the 70% VC:30% Urea application could be attributed to the increase in the soil OM from the VC, as reported by Terefe *et al*. (2024b). The increase in the CEC value of soil in the increased proportion of VC than urea was supported by Lemessa (2020). In addition, Habtamu *et al.*(2024) also reported that the application of VC to the soil improves soil porosity to promote better root growth and development, and increases the CEC value of the soil.

The result of the current study also showed that the soil OC varies among the treatments used (Table 4). The full-dose (100%) application of VC in the current study increased the soil OC by 53.49% and 16.67% compared to the control treatment and the 100% application of urea, respectively. A similar result was found by Habtamu *et al.* (2024), who found that the sole application of VC improved the OC more than the control treatment and the sole application of urea. Similarly, experiments conducted in other countries like Nepal (Ghimire *et al.*, 2023), Bangladesh (Mukta *et al.*, 2016), and in Pakistan (Hammad *et al*., 2020) proved that the amendments of organic fertilizer to the soil improve the organic carbon content more than the unfertilized plots. These align with Terefe *et al.* (2024b), who reported a 39% increase in soil carbon content after applying VC and mineral fertilizer.

In the current study, variation in soil pH was observed between altitudes (Table 3). Significantly ($P<0.001$) higher soil pH was recorded from the soil in the mid-altitude (below 1500 m.a.s.l.) than in the high-altitude location (above 1500 m.a.s.l). The improvement in the soil pH, in the mid-altitude location, might be due to the presence of basic parent materials like basalt and limestone, while the basic cations in the high altitudes leach. The main reason for the decrease in soil pH is the reduction or leaching of OM by the high rainfall. On the other hand, the improvements of forage grass growth in the midland and the ground cover provided by forage grass can reduce runoff, soil erosion, and associated basic cations that result from improved soil organic matter and soil pH, which could be attributed to the increase in the pH level of the soil (Kumar *et al.,* 2019). Variation was also observed in the TN contents of soil between altitudes (Table 3). The soil at the mid-altitude location was generally more fertile, showing improvement in OC, TN, AvP, OM, and CEC (Table 3). The result of the current study was consistent with the findings of Walie *et al*. (2022), who reported improved soil chemical properties in the mid-altitude location than at higher altitudes.

Variations in the chemical properties of soil were observed among the forage grasses cultivated in the current study (Table 3). Among the forage grasses examined in the current study, Guinea grass improved the soil pH more, which could be due to the horizontal growing behavior of the grass, which covers a wider area, indirectly reducing runoff and soil losses. Planting of Desho grass, on the other hand, exhibited the highest %OC, TN, and CEC, indicating that planting of Desho grass is more beneficial for soil fertility compared with planting of Napier and Guinea grasses in the Ethiopian farming system. This might be attributed to, Desho grass has more tillers and roots (Table 4), which can minimize erosion and maintain soil structure, which indirectly affects the soil parameters (Welle *et al.,* 2006). Similar work was reported by Walie *et al*. (2022).

Forage growth characteristics and Dry matter yield (t ha^{-1}).

We initially assumed that either individual or combined application of VC and urea in different proportions would improve the forage grasses' growth characteristics and DMY (t ha^{-1}). Consistent with our assumptions, the current finding showed improvements in the growth performances and DMY (t ha^{-1}) of forage grasses due to the application of VC and urea. Improved morphology in the combined application than the individual application could be attributed to the synergistic effects of VC and urea, which complement each other in soil nutrient release patterns (Schulz and Glaser., 2012). While urea offers immediate N to the soil, VC slowly releases nutrients over time, ensuring a continuous nutrient supply throughout the plant growth cycle (Getie *et al.*, 2022; Qasim *et al*., 2023). This complementarity enhances the nitrogen use efficiency of plants and supports sustainable plant growth (Ghimire *et al.,* 2023). In line with our findings, Lemmesa (2020) found an improvement in the morphological parameters of Panicum *coloratum* grass with combined urea and VC application. Similarly, studies on food crops by Jin *et al*. (2022); Qasim *et al*. (2023); Sher *et al.* (2022); and Terefe *et al.*(2024b) also, confirm the positive impacts of integrating organic and inorganic fertilizers on plant morphology.

The absence of synergetic effects on the individual application of either VC or urea, on the other hand, could be the reason for the decrement in the morphological parameters of forage grasses. Comparably, forage grass responds better to sole urea compared to VC application, likely due to the quick availability and solubility of nitrogen in urea *(*Elias *et al.,* 2023). In contrast, VC's slow nutrient release pattern and lower N content contributed to the lower performance of forage grasses. The lowest morphological performance of forage grass was observed in the sole application of VC because of the slower nutrient-release nature of VC Elias *et al.*(2023), lower N content, and inconsistent nutrient distribution. In general, the fertilizer treatment improved the agronomic performance of forage grass over the control group. Unsurprisingly, the control treatment showed the poorest growth, likely due to nutrient depletion over time; hence, plants showed underdeveloped growth.

In forage production, DMY is the most important indicator of productivity. In this study, the combined application of urea and VC significantly improved the DMY (t ha^{-1}) of forage grass. The highest DMY (t ha^{-1}) of forage grass was recorded from the combined application compared to the individual application, while the lowest DMY (t ha^{-1}) was recorded from the control treatment (Table 4). The increase in DMY (t ha^{-1} might be due to the synergetic nutrient release patterns. Additionally, increased tiller numbers, leaf counts, plant height, and leaf length in the combined treatment group may have contributed to the higher DMY (t ha^{-1}).

Environmental factors such as altitude also played a significant role in the performance of forage grasses. Forage grass morphological characteristics and DMY were generally higher in mid-altitude locations compared to high-altitude sites, which was supported by the previous report of Walie *et al*. (2022) for Desho and Napier grass and Asmare *et al.* (2017) for Desho grass. This trend also aligns with the earlier conclusion by Fikadu *et al*. (2022) and Desta *et al*. (2023). The main reason explaining this pattern is that variations in environmental conditions, such as temperature, soil types, and precipitation, occur across different altitudinal zones. On the other hand, previous research conducted in Ethiopia has indicated a decrease in biomass production of forage grass with increasing altitudes/elevations (Fikadu *et al.*, 2022; Walie *et al*., 2022).

Morphological growth variations of forage grass were also observed among Desho, Guinea, and Napier grass, similar to the report by Walie *et al.* (2022). The reason might be attributed to a genetic variation and potential between the forage grass species, to extract minerals from the soil, the plant's potential to adapt to environmental conditions, and the capacity to interact with other species, such as soil microbes (Welle *et al.*, 2006). In the current study, Napier grass yielded the highest DMY (t ha^{-1}) followed by Guinea and Desho grass, respectively. These findings align with Walie *et al*. (2022), who also reported superior DMY performance in Napier compared to Desho grass, likely due to their differences in genetic potential, growth habit, and biomass accumulation (Bantihun et al., 2022). Bantihun *et al*. (2022) also reported a higher DMY t ha^{-1} from Napier grass than Desho grass in the same management system.

Root characteristics of forage grasses

Similar to the morphological and dry matter yield of forage grasses, the root characteristics of forage grasses were affected by the application of different rates of VC and urea. The longer RL in Napier grass compared to Desho and Guinea grass in our experiment can be attributed to a combination of genetic parameters, root structure, soil exploration abilities, and adaptation to environmental conditions. In line with our findings, Walie *et al.* (2022) found that higher RL in Napier grass than in Desho grass was observed in the same management system. These factors collectively contribute to superior root growth and development observed in Napier grass, making it a preferred choice for forage production. The reason behind the higher root length in the mid-altitude than at higher altitudes is similar to other morphological parameters, dry matter yield, and is similar to the finding of (Walie *et al.*, 2022). Significant improvement in RLPP and NRPP in fertilized treatment than unfertilized treatment could be due to the enhancement of soil structure by increasing the availability of organic matter, creating favorable conditions for root propagation.

CONCLUSIONS

The result of the current experiment showed that the combined application of vermicompost and urea significantly improves the morphological parameters such as PH, NTPP, NLPP, LWPP, NRPP, and RLPP, as well as the DMY (t ha^{-1}) of forage grasses. The highest pH, OC, CEC, TN, AvP, and OM of soil were obtained from the plots treated with 100% VC, followed by the combined application. Napier grass produced the highest DMY (t ha^{-1}) among the forage grass species examined, followed by Guinea and Desho grass, respectively. Additionally, the forage grass performed better at the mid-altitude location than the high-altitude one. These findings highlight the potential of integrated nutrient management using vermicompost and urea to enhance forage yield and improve soil health, thereby contributing to the development of a sustainable and environmentally friendly livestock production system. Further long-term studies are recommended to evaluate the integration of vermicompost with other organic fertilizers, such as compost, biochar, and liquid fertilizers, and their effects on forage productivity as well as live animal performance.

Acknowledgments
The authors would like to acknowledge Bahir Dar University and Andassa Livestock Research Center for supporting all materials required for the current study.

Funding. The author received funding from Bahir Dar University for this work.

Conflicts of Interest. The authors declare that they have no conflicts of interest

Compliance with ethical standards. This research did not involve human participants or animals. All fieldwork and data collection were conducted following standard agronomic and environmental research practices.

Data availability. The data supporting the findings of this study are available from the corresponding author upon reasonable request: eniyewu@gmail.com

Author's contribution (CRediT). E. Mekcha – Conceptualization; Investigation; Methodology; Formal analysis; Data curation; Writing, reviewing and editing. **B. Asmare** – Supervision; Writing review and editing; Conceptualization; Investigation; Methodology, and Validation. **N. Beyero** – Conceptualization; Investigation; Methodology; Validation; Supervision; Writing review and editing. **S. Mekuriaw –** Methodology; Data curation; Formal analysis; Validation.

REFERENCES

Abera, M., Tolera, A., Nurfeta, A. and Geleti, D., 2021. Production, Utilization, and Constraints of Desho Grass (*Pennisetum Glaucifolium)* as Livestock Feed in Ethiopia. *Online Journal of Animal and Feed Research*, 11(6), pp. 196–205. https://doi.org/10.51227/OJAFR.2021.29

Adhikary, S., 2012. Vermicompost, the Story of Organic Gold: A Review. *Agricultural Science.* 3, pp. 905–917. https://doi.org/10.4236/as.2012.37110

Alem, R. and Fassil, K., 2015. Agronomic performance of integrated use of organic and inorganic fertilizers on rice (*Oryza sativa L.*) in Tselemti District of North-Western Tigray, Ethiopia. *Journal of Environment and Earth Science*, *5*(9), pp. 30–41. http://www.iiste.org/Journals/index.php/JEES/article/view/22337/22966

Alemie, D. K. and Gebremedhin, H., 2019. Availability of Fodder Trees and Shrubs Integrated Into Agricultural Systems in Eastern Hararghe, Ethiopia. *Journal of Agricultural Science*, 11(5), pp. 506-514 https://doi.org/10.5539/jas.v11n5p506

Andrade, M.M.M.; Stamford, N.P.; Santos, C.E.R.S.; Freitas, A.D.S.; Sousa, C.A.; and Junior, M.A.L. 2013. Effects of Biofertilizer with Diazotrophic Bacteria and Mycorrhizal Fungi in Soil Attribute, Cowpea Nodulation Yield and Nutrient Uptake in Field Conditions. *Scientia Horticulturae* 162, pp. 374–379. http://dx.doi.org/10.1016/j.scienta.2013.08.019

Aslam, Z. and Ahmad, A., 2020. Effects of Vermicompost, Vermi-tea and Chemical Fertilizer on Morpho-physiological Characteristics of Maize (*Zea mays L.*) in Suleymanpasa District, Tekirdag of Turkey. *Journal of Innovative Sciences*, 6(1), pp.41-46. https://doi.org/10.17582/journal.jis/2020/6.1.41.46

Aslam, Z., Ahmad, A., Mushtaq, Z., Liaquat, M., Hussain, T., Bellitürk, K., Awad Alahmadi, T., Ansari, M. J., Ur Rahman, S. and Du, Z., 2024. Evaluating the integration of vermicompost with synthetic fertilizer and compost on mung bean (*Vigna radiata L.*). *Archives of Agronomy and Soil Science*, 70, pp. 1–14. https://doi.org/10.1080/03650340.2023.2301338

Asmare, B., Demeke, S., Tolemariam, T., Tegegne, F., Haile, A. and Wamatu, J., 2017. Effects of altitude and harvesting dates on morphological characteristics, yield, and nutritive value of desho grass (*Pennisetum pedicellatum Trin.*) in Ethiopia. *Agriculture and Natural Resources*, 51(3), pp. 148–153. https://doi.org/10.1016/j.anres.2016.11.001

Assefa, S., 2019. The Principal Role of Organic Fertilizer on Soil Properties and Agricultural Productivity -A Review. Agricultural Research and Technology:*Agricultural research and Technology*, 22(2), pp. 44-50 https://doi.org/10.19080/artoaj.2019.22.556192

Ayele, J., Tolemariam, T., Beyene, A., Tadese, D. A. and Tamiru, M., 2021. Assessment Of Livestock Feed Supply And Demand Concerning Livestock Productivity In Lalo Kile District Of Kellem Wollega Zone, Western Ethiopia. *Heliyon*, 7(10), p.e08177. https://doi.org/10.1016/j.heliyon.2021.e08177

Balehegn, M., Duncan, A., Tolera, A., Ayantunde, A. A., Issa, S., Karimou, M., Zampaligré, N., André, K., Gnanda, I., Varijakshapanicker, P., Kebreab, E., Dubeux, J., Boote, K., Minta, M., Feyissa, F., and Adesogan, A. T. 2020. Improving adoption of technologies and interventions for increasing supply of quality livestock feed in low- and middle-income countries. *Global Food Security*, 26 (October 2019), p.100372. https://doi.org/10.1016/j.gfs.2020.100372

Bantihun, A., Asmare, B. and Mekuriaw, Y. 2022. Comparative Evaluation of Selected Grass Species for Agronomic Performance, Forage Yield, and Chemical Composition in the Highlands of Ethiopia. *Advances in Agriculture*, 2022 pp. 1-13. https://doi.org/10.1155/2022/6974681

Bedaso, N. H., Bezabih, M., Zewdu Kelkay, T., Adie, A., Khan, N. A., Jones, C. S., Mekonnen, K. and Wolde-meskel, E., 2022. Effect of fertilizer inputs on productivity and herbage quality of native pasture in degraded tropical grasslands. *Agronomy Journal*, 114(1), pp. 216–227. https://doi.org/10.1002/agj2.20862

Berhe, M., Oniki, S., Negash, T. and Etsay, H., 2024. What determines livestock feed and marketing? Insights from rural Ethiopia. *Scientific African*, 24 (March), p. e02143. https://doi.org/10.1016/j.sciaf.2024.e02143

Bezabih, M. Abera, D., Adie, A., Lefore, N. and Jones, C., 2020. Analysis of stakeholder's roles and relationships in the feed value chain in Ethiopia. ILRI Discusion paper 39. Nairobi, Keny:ILRI. https://www.ilri.org/knowledge/publications/analysis-stakeholders-roles-and-relationships-feed-value-chain-ethiopia

CSA., 2021. Federal Democratic Republic of Ethiopia Central Statistical Agency Agricultural Sample Survey 2020 / 21 [2013 E . C .] Volume II Report On. II (March)

Desta, A.. 2015. Effects of Organic and Inorganic Fertilizers on Selected Soil Properties after Harvesting Maize at Antra Catchment, Northwestern Ethiopia. *International Invention Journal of Agricultural and Soil Science*, 3(5), pp. 68–78.

Diriba, G. and Adugna, T., 2013. Effect of age of regrowth on yield and herbage quality of *Panicum coloratum* under sub-humid climatic conditions of Ethiopia. *African Journal of Agricultural Research*, 8(46), pp.5841-5844. http://www.academicjournals.org/article/article1386063399_Geleti%20and%20Tolera.pdf

Dubey, R.K., Dubey, P.K., Chaurasia, R., Singh, H.B. and Abhilash, P.C. 2020 Sustainable Agronomic Practices for Enhancing the Soil Quality and Yield of Cicer *arietinum L.* under Diverse Agroecosystems. *Journal of Environmental management.* pp. 262, p.110284. https://doi.org/10.1016/j.jenvman.2020.110284

Edwards, C.A., Arancon, N.Q., Vasko-Bennett, M., Askar, A. and Keene, G. 2010 Effect of aqueous extracts from vermicompost on attacks by cucumber beetles (*Acalymna vittatum*) (Fabr.) on cucumbers and tobacco hornworm (*Manduca sexta*) (L.) on tomatoes., *Pedobiologia,* 53, pp. 141–148. https://doi.org/10.1016/j.pedobi.2009.08.002

Elias, E., Okoth, P. F., Stoorvogel, J. J., Berecha, G., Mellisse, B. T., Mekuriaw, A., Gebresamuel, G., Selassie, Y. G., Biratu, G. K. and Smaling, E. M. A., 2023. Cereal yields in Ethiopia relate to soil properties and N and P fertilizers. *Nutrient Cycling in Agroecosystems*, 126(2–3), pp. 279–292. https://doi.org/10.1007/s10705-023-10291-z

Feyissa, F., Kebede, G., Geleti, D., Assefa, G. and

Mengistu, A., 2022. Improved Forage Crops Research and Development in Ethiopia: Major Achievements, Challenges, and the Way Forward. *OMO International Journal of Sciences*, 5(2), pp. 36–69. https://doi.org/10.59122/135be51

Fikadu, T., Tesfaye, W., Bekuma, W.and Furgasa, M., 2022. (*Pennisetum Pedicellatum*) for Forage Biomass Yield and Nutritional Quality at Midland and Highland Agro-Ecologies of Eastern Hararghe, Ethiopia. *Forage Research*, 47(4), pp. 480–486. http://doi.org/10.11648/j.ajaf.20221005.16

Getaneh, S., 2021. Drivers to Adoption of Irrigated Fodder Technologies and Its Impact on þÿSmallholder Farmers Income : Evidence from Innovation Lab for Small-Scale Irrigation Project Sites, Ethiopia. http://ir.bdu.edu.et/handle/123456789/12945

Getie, A., Asmare, B. and Mekuriaw, Y., 2022. Effects of fertilizer type on morphological characteristics, forage yield, seed yield, and qualities of Rhodes grass (*Chloris gayana k*) in northwestern Ethiopia. *Scientific Papers: Animal Science and Biotechnologies*, 55(1), pp. 1-2. http://spasb.ro/index.php/spasb/article/view/2797%0Ahttps://www.cabdirect.org/cabdirect/abstract/20220240118

Ghimire, S., Dhami, D., Shrestha, A., Budhathoki, J., Maharjan, M., Kandel, S. and Poudel Chhetri, B., 2023. Effectiveness of different combinations of urea and vermicompost on the yield of bitter gourd (*Momordica charantia*). *Heliyon*, 9(8), p.e18663. https://doi.org/10.1016/j.heliyon.2023.e18663

Habtamu, M., Elias, E., Soromessa, T., and Argaw, M., 2024. Effects of Integrated Application of Vermicompost and Inorganic Fertilizers on Selected Soil Characteristics and Productivity of Wheat (*Triticum aestivum L.*) and Faba Bean (Vicia faba L.) in Dire and Legedadi Watersheds of Ethiopia. *Applied and Environmental Soil Science*, 2024, pp.3163750. https://doi.org/10.1155/2024/3163750

Hammad, H.M., Khaliq, A., Abbas, F., Farhad, W., Fahad, S., Aslam, M., Shah, G.M., Nasim, W., Mubeen, M. and Bakhat, H.F., 2020. Comparative Effects of Organic and Inorganic Fertilizers on Soil Organic Carbon and Wheat Productivity under Arid Region. *Communications in Soil Science and Plant Analysis*, 51(10), pp. 1406–1422. https://doi.org/10.1080/00103624.2020.1763385

Jaganathan, D., Thamban, C., Jose, C.T., Jayasekhar, S. and Anithakumari, P., 2013. Analysis of organic farming practices in coconut in South India. *Journal of Plantation Crops,* 41(1), pp. 71-79. https://updatepublishing.com/journal/index.php/JPC/article/view/5905

Jin, N., Jin, L., Wang, S., Li, J., Liu, F., Liu, Z., Luo, S., Wu, Y., Lyu, J.and Yu, J. 2022. Reduced Chemical Fertilizer Combined With Bio-Organic Fertilizer Affects the Soil Microbial Community and Yield and Quality of Lettuce. *Frontiers in Microbiology*, 13 (April), pp. 1–14. https://doi.org/10.3389/fmicb.2022.863325

Joshi, R., Vig, A.P. and Singh, J.,2013. Vermicompost as soil supplement to enhance growth, yield and quality of Triticum aestivum L.: a field study. *International Journal Of Recycling of Organic Waste in Agriculture*, 2(1). https://doi.org/10.1186/2251-7715-2-16

Kumar, A., Akram, P. and Panday, A.V.K. 2019. Soil Binding Capacity of Different Forage Grasses in Terms of Root Reinforcement Ability toward Soil Slope Stabilization. *Indian Journal of Hill Farming*, 32(1), pp. 137–143.

Landon, J.R., 2015. Booker Tropical Soil Manual, a Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics. London:Routledge. https://doi.org/10.4324/9781315846842

Lemmesa, T., 2020. Effect of Different Rates of Vermicompost and Inorganic Fertilizer on Agronomic Performance, Biomass Yield and Chemical Composition of *Panicum Coloratum* Grass in Jimma South West, Ethiopia. https://repository.ju.edu.et//handle/123456789/5683.

Markam, S., 2021. Review: Vermicompost, its importance, and benefits in agriculture. *Agraarteadus*, 30(2), 93–98. https://doi.org/10.15159/jas.19.19

Mengistu, A, G. Kebede, Assefa, G and Feyissa, F. 2017. Descriptions and Characteristics of

Cultivated Forage Crops Growing under Different Agro-Ecological Zones in Ethiopia, review article. *International Journal of Agriculture and Biosciences,* 6(5), pp. 238–247. https://www.ijagbio.com/pdf-files/volume-6-no-5-2017/238-247.pdf

Mergia, A, Adugna, T. and Ajebu, N., 2022. Effect of Fertilizer Level and Harvesting Date on Yield and Nutritive Value of Desho Grass (*Pennisetum pedicellatum*) in Hula and Bule districts of the Southern Region of Ethiopia. *Ethiopian Journal of Animal Production*, 20 (1), pp. 18-28. https://www.ajol.info/index.php/ejap/article/view/255683

Mukta, S., Rahman, M. and Mortuza, M., 2016. Yield and Nutrient Content of Tomato as Influenced by the Application of Vermicompost and Chemical Fertilizers. *Journal of Environmental Science and Natural Resources*, 8(2), pp. 115–122. https://doi.org/10.3329/jesnr.v8i2.26877

Notenbaert, A.M.O., Douxchamps, S., Villegas, D.M., Arango, J., Paul, B.K., Burkart, S., Rao, I., Kettle, C.J., Rudel, T., Vázquez, E., Teutscherova, N., Chirinda, N., Groot, J.C.J., Wironen, M., Pulleman, M., Louhaichi, M., Hassan, S., Oberson, A., Nyawira, S.S. and Peters, M., 2021. Tapping Into the Environmental Co-benefits of Improved Tropical Forages for an Agroecological Transformation of Livestock Production Systems. *Frontiers in Sustainable Food Systems*, 5 (November). https://doi.org/10.3389/fsufs.2021.742842

Okalebo, J.R., Gathua, K.W. and Paul, L.W., 2002. Laboratory Methods of Soil and Plant Analysis: A Working Manual the Second Edition. *SACRED Africa, Kenya Any*, *Second Edi*, pp. 1–131.

Oyege, I. and Balaji Bhaskar, M.S., 2023. Effects of Vermicompost on Soil and Plant Health and Promoting Sustainable Agriculture. *Soil Systems*, 7(4), p.101. https://doi.org/10.3390/soilsystems7040101

Panda, A.K., Mishra, R., Dutta, J., Wani, Z.A., Pant, S. and Bisht, S.S., 2022. Impact of Vermicomposting on Greenhouse Gas Emission : A Short Review. *Sustainability,* 14, p.11306. https://doi.org/10.3390/su141811306

Paul, B.K., Groot, J.C.J., Maass, B. L., Notenbaert, A.M.O., Herrero, M. and Tittonell, P.A., 2020. Improved feeding and forages at a crossroads: Farming systems approaches for sustainable livestock development in East Africa. *Outlook on Agriculture*, 49(1), pp. 13–20. https://doi.org/10.1177/0030727020906170

Qasim, M., Ju, J., Zhao, H., Bhatti, S.M., Saleem, G., Memon, S.P., Ali, S., Younas, M.U., Rajput, N. and Jamali, Z. H., 2023. Morphological and Physiological Response of Tomato to Sole and Combined Application of Vermicompost and Chemical Fertilizers. *Agronomy*, 13(6), p. 1508. https://doi.org/10.3390/agronomy13061508

Richter, J. and Roelcke, M., 2000. The N-cycle as determined by intensive agriculture - Examples from central Europe and China. *Nutrient Cycling in Agroecosystems*, 57(1), pp. 33–46. https://doi.org/10.1023/A:1009802225307

Sabrina, D.T., Hanafi, M.M.; Gandahi, A.W., Muda Mohamed, M.T. and Abdul Aziz, N.A. 2013. Effect of Mixed Organic-Inorganic Fertilizer on Growth and Phosphorus Uptake of Setaria Grass (‘*Setaria splendida’*). *Australian Journal of Crop Science*, 7, pp. 75–83.

Schulz, H. and Glaser, B., 2012. Effects of biochar compared to organic and inorganic fertilizers on soil quality and plant growth in a greenhouse experiment. *Journal of Plant Nutrition and Soil Science*, 175(3), pp. 410–422. https://doi.org/10.1002/jpln.201100143

Shapiro B., G. and Gebru, S.D. 2020. Ethiopia livestock master plan: Roadmaps for growth and transformation. Nairobi, Kenya:ILRI. https://hdl.handle.net/10568/68037

Sher, A., Adnan, M., Sattar, A., Ul-Allah, S., Ijaz, M., Hassan, M.U., Manaf, A., Qayyum, A., Elesawy, B.H., Ismail, K.A., Gharib, A.F., and Askary, A.El., 2022. Combined Application of Organic and Inorganic Amendments Improved the Yield and Nutritional Quality of Forage Sorghum. *Agronomy*, 12(4), pp.896. https://doi.org/10.3390/agronomy12040896

Shifa, S., Worku, M. and Beyene, A., 2024. Co-application of compost and biochar improves soil properties and Desho grass growth on acidic soils in a tropical environment of

Southwestern Ethiopia. *Cogent Food and Agriculture*, 10(1), p.2290338. https://doi.org/10.1080/23311932.2023.2290338

Singh, S. and Misal, N. B., 2022. Effect of Different Levels of Organic and Inorganic Fertilizers on Maize (*Zea mays L.*). *Indian Journal of Agricultural Research*, 56(5), pp.562–566. https://doi.org/10.18805/IJARe.A-5231

Terefe, Z., Feyisa, T., Molla, E. and Ejigu, W., 2024a. Effects of vermicompost and mineral fertilizers on soil properties, malt barley (*Hordeum distichum L.*) yield, and economic benefits. *Agrosystems, Geosciences and Environment*, 7(3), pp. 1–15. https://doi.org/10.1002/agg2.20550

Terefe, Z., Feyisa, T., Molla, E., and Ejigu, W., 2024b. Effects of vermicompost and mineral fertilizers on soil properties, malt barley (*Hordeum distichum L.*) yield, and economic benefits. *Agrosystems, Geosciences and Environment*, 7(3), pp. e20550. https://doi.org/10.1002/agg2.20550

Tessema, Z.K., de Boer, W.F., Baars, R.M.T. and Prins, H.H.T., 2011. Changes in soil nutrients, vegetation structure, and herbaceous biomass in response to grazing in a semi-arid savanna of Ethiopia. *Journal of Arid Environments*, 75(7), pp. 662–670. https://doi.org/10.1016/j.jaridenv.2011.02.004

Tolera, A., Vernooij, A. and Berhanu, T., 2019. Status of Introduction and Distribution of Fodder Seeds and Planting Materials in Selected Districts of Amhara, Oromia, SNNP, and Tigray Regional States. *Wageningen UR Livestock Research Report*, *No.1152*, 45 pp.

Walie, M., Tegegne, F., Mekuriaw, Y., Tsunekawa, A., Kobayashi, N., Ichinohe, T., Haregeweyn, N., Tassew, A., Mekuriaw, S., Masunaga, T., Okuro, T., Tsubo, M., Meshesha, D.T. and Adego, E., 2022. Effects of farmyard manure and Desmodium intercropping on forage grass growth, yield, and soil properties in different agro-ecologies of Upper Blue Nile basin, Ethiopia. *Cogent Food and Agriculture*, 8(1), p.2082041. https://doi.org/10.1080/23311932.2022.2082041

Welle, S., Chantawarangul, K. and Nontananandh, S., 2006. Effectiveness of Grass Strips as Barrier Against Runoff and Soil Loss in Jijiga Area. Effectiveness of Grass Strips as Barrier Against Runoff and Soil Loss in Jijiga Area, *Journal of Natural Science 558*, pp. 549–558.

Yadav, A., Bhuj, B.D., Ram, S., Singh, C.P., Dhar, S., Yadav, R.K., Singh, M. and Ashok, K., 2021. Organic farming for sustainable agriculture: A review. *Annals of the Romanian Society for Cell Biology*, 25(6), pp. 8088–8123. http://annalsofrscb.ro/index.php/journal/article/view/6999