**Dissertation Ref. No. ____**

# EVALUATION OF FODDER YIELD, CHEMICAL COMPOSITION AND FEEDING VALUE OF *Urochloa mutica* (DZF-483) SUBJECTED TO DIFFERENT FERTILIZER REGIMES, PLANT SPACING AND HARVESTING AGE

PhD Dissertation

By

Gelane Kumssa Effa

College of Veterinary Medicine and Agriculture

Department of Animal Production Studies

PhD Program in Animal Production

April, 2026

Bishoftu, Ethiopia

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A dissertation submitted to the College of Veterinary Medicine and Agriculture of Addis Ababa University in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in Animal Production

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As members of the Examining Board of the final PhD open defense, we certify that we have read and evaluated the Dissertation prepared by Gelane Kumssa Effa titled: **'Evaluation of Fodder Yield, Chemical Composition and Feeding Value of *Urochloa mutica* (DZF-483) Subjected to Different Fertilizer Regimes, Plant Spacing and Harvesting Age'** and recommend that it be accepted as fulfilling the dissertation requirement for the **Doctor of Philosophy in Animal Production.**

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# DEDICATION

*This dissertation is dedicated to my daughter Soreti Biruk Zewdie, who was born during the study time and endured greater suffering as a result of my inattention.*

## STATEMENT OF THE AUTHOR

I first, declare that this dissertation is my bona fide work and that all sources of materials used for this dissertation have been duly acknowledged. This dissertation has been submitted to the requirements for PhD degree at Addis Ababa University, College of Veterinary Medicine and Agriculture and is deposited at the University's Library to be made available to borrowers under rules of the library. I solemnly declare that this dissertation is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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## BIOGRAPHICAL SKETCH

The author of the PhD dissertation was born in January 1990 in the vicinity of Ginchi town, located in the West Shoa Zone of Ethiopia. Her early education began at Gura Awash Elementary School, followed by secondary education at Ginchi Secondary and Preparatory School. After completing her preparatory education, she enrolled at Ambo University, where she earned a Bachelor of Science degree in Animal Sciences in 2011. Upon graduation, she became employed as a junior researcher in feed and nutrition at the Ethiopian Institute of Agricultural Research, specifically at the Bishoftu Center. In 2015, she advanced her studies by joining the School of Graduate Studies within the College of Agriculture and Range Sciences at Haramaya University, successfully obtaining a Master of Science degree in Animal Production in July 2017. Following this achievement, she returned to work at the Bishoftu Agricultural Research Center, where she continues her professional career. In addition to her academic and professional pursuits, the author is married and is a mother to a son and three daughters.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| ADF | Acid detergent fiber |
| ADFI | Acid detergent fiber intake |
| ADL | Acid detergent lignin |
| ADLI | Acid detergent lignin intake |
| AHY | Adjusted herbage yield |
| ALRC | Andassa Livestock Research Center |
| AMY | Adjusted milk yield |
| ANOVA | Analysis of variance |
| AOAC | Association of Official Analytical Chemists |
| ATA | Agricultural Transformation Agency |
| BARC | Bishoftu Agricultural Research Center |
| CIMMYT | *Centro Internacional de Mejoramiento de Maíz y Trigo* (in Mexico) |
| cm | Centimeter |
| CP | Crude protein |
| CPI | Crude protein intake |
| CPY | Crude protein yield |
| CSA | Central Statistical Authority |
| DAP | Diammonium phosphate |
| DM | Dry matter |
| DMI | Dry matter intake |
| DMI | Dry matter intake |
| DMY | Daily milk yield |
| DMY | Dry matter yield |
| DOMD | Digestible organic matter in the dry matter |
| ETB | Ethiopian Birr |
| FAO | Food and Agriculture Organization of the United Nations |

## LIST OF ABBREVIATIONS (Continued)

| | |
|---|---|
| GFB | Gross field benefit |
| HARC | Holetta Agricultural Research Center |
| ICIPE | International Center of Insect Physiology and Ecology |
| ICPALD | International Centre for Pastoral Areas and Livestock Development |
| ILRI | International Livestock Research Institute |
| IVDMD | *In vitro* dry matter digestibility |
| LA | Leaf area |
| LL | Leaf length |
| LLPP | Leaf length per plant |
| LSR | Leaf to stem ratio |
| ME | Metabolizable energy |
| Mg | Magnesium |
| MoA | Ministry of Agriculture of the Federal Democratic Republic of Ethiopia |
| MRR | Marginal rate of return |
| N | Nitrogen |
| NB | Net benefit |
| NDF | Neutral detergent fiber |
| NGO | No Governmental Organization |
| NIRS | Near-infrared reflectance spectroscopy |
| NLPP | Number of leaves per plant |
| NPK | Nitrogen, Phosphorus, Potassium |
| NPS | Nitrogen, Phosphorus, Sulphur |
| NRPP | Number of roots per plant |
| NTPP | Number of tillers per plant |

## LIST OF ABBREVIATIONS (Continued)

| | |
|---|---|
| OM | Organic matter |
| PC | Plot cover |
| PH | Plant height |
| RGD | Regrowth rates |
| RLPP | Root length per plant |
| SAS | Statistical Analysis System |
| SNF | Solids- not- fat |
| TS | Total solids |
| TSNF | Total-solids-not-fat |
| TVC | Total variable cost |
| UHY | Unadjusted herbage yield |
| UMY | Unadjusted milk yield |

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**Gelane Kumssa Effa**
**PhD Dissertation**
**Addis Ababa University**

## ABSTRACT

*With significant biomass yields and nutritional value, Urochloa mutica showed promise in addressing the current feed scarcity and livestock productivity. However, while using Urochloa for the best feeding results, it is crucial to take into account the significant agronomic aspects, particularly the type of fertilizer with the optimum rate, the stage of maturity, and the spacing between plants. Thus, the purpose of this study was to evaluate the effects of fertilizer type, plant spacing, and harvesting age on Urochloa mutica growth, yield, and nutritional composition, specifically with regard to dairy cow feed. It contained three experiments: the first examined different fertilizer treatments (sole vermicompost, sole NPS, combined vermicompost and NPS, and no fertilizer), while the second explored various intra-row plant spacings (20 cm, 35 cm, and 50 cm) and harvesting ages or clearing date (60, 90, and 120 days). Both experiments were arranged as randomized complete block designs with three replications on a plot size of 12 m². Key information collected were plot cover, plant height, number of tillers and leaves, root characteristics, leaf-to-stem ratio, dry matter yield, and forage chemical composition. The third experiment focused on the effects of Urochloa mutica hay supplemented with varying levels of concentrate on feed intake, milk yield, and composition of high-grade dairy cows, employed a crossover design with four treatment groups. Results indicated that the blended NPS and varying combinations of vermicompost and NPS fertilizers did not prominently differ in terms of agronomic and nutritional parameters, with the best runner-up treatment a mixture of 75% NPS and 25% vermicompost. Morphologically, late maturity plants displayed superior growth, while wider plant spacings were beneficial, except for root numbers, and the dry matter yield (DMY) improved with narrower spacing and later harvests. In the animal feeding experiment,* *higher dry matter (12.8 kg/day) and crude protein (1.85) intakes observed in cows on treatments $T_1$ (Urochloa mutica + 0.5 kg concentrate per 1 kg milk yield. In treatment $T_2$ relatively better dry matter (12.7 kg per day) and crude protein (1.67) intake and, optimal milk production (10.9L) with significant protein content (4.5%) were observed, while economically, it provided the highest net benefit. Thus, the study concludes that, $T_4$ (75% NPS + 25% vermicompost) fertilizer can substitute NPS fertilizer with better yield and quality. Besides narrow plant spacing (20 cm), and a later harvesting age for better yield are recommended. Additionally, to maximize milk output, a diet of Urochloa mutica supplemented with 0.4 kg of concentrate per 1 kg of milk yield for better return with high MRR is advocated for lactating high grade dairy cows in the study area and similar agro-ecological zones.*

**Key words:** Cross-bred dairy cows, fertilizer, harvesting age, plant spacing and *Urochloa mutica*.

# 1. INTRODUCTION

Ethiopia has the largest livestock population in Africa, possesses 70.3 million cattle, 42.9 million sheep, 52.5 million goats and 8.1 million camels (MOA, 2023) which supporting the livelihoods of more than 80 percent of rural communities by providing income, milk, meat, manure, and draught power while also generating foreign exchange earnings (Behnke, 2010; ICPALD, 2013; Aleme and Lemma, 2015). Moreover, the sector is evolving, driven by a rapidly growing demand for livestock products. However, the productivity per animal is very low, and the contribution to the overall economy is much lower than expected. The average daily milk yield of indigenous dairy cows is 1.5 liter in rural pastoralist system and approximately 7.3 liter for cross-bred cows. Per capita consumption of meat and milk is approximately 8kg and 19kg per year respectively, and relatively low compared to other developing countries due to low productivity of the livestock in Ethiopia (FAO, 2025). Among many factors constraining the development of the livestock sector, feed shortage, both in quantity and quality, has remained the main restraining factor hindering the livestock productivity subsector in the country (Yayneshet, 2010; Alemayehu and Getnet, 2012). The major feed resources include crop residues (49%), natural pasture (30%), agro-industrial (11%) byproducts and improved forage contribute 10% (Belay and Geert, 2021).

Indigenous pastures contributed much to livestock feed supply; current trends indicated that they are seriously overstocked and the existing grazing lands are shrinking from time to time due to rapid human population growth and encroachment of croplands due to the need to nourish the increasing human population. Furthermore, feed supply from natural pasture fluctuated according to the seasonal rainfall dynamics (Yayneshet, 2010). In developing countries, responding to the ever-increasing demand for animal products with alternative strategies that improve the high-protein feed supply for livestock is a priority area in the development of feed resources (Getnet, 2007).

Improved forage crops can help not only mitigate livestock feed shortages but also reduce pressure on natural pastures (Zerihun and Getachew, 2013). The production of a sufficient quantity of good-quality forages for supplementation of native pastures, roughages, and crop residues is the widely advocated strategy to overcome the feed scarcity (Alemayehu *et al*., 2016). They are surely a cost-effective feed instead of commercial concentrates. Concentrate replacement with improved forages from 30% to 70% has been reported to reduce up to 30% of production cost in the dairy cattle diet (Sanh *et al*., 2002). However, adoption rates remain low (CSA, 2022; Mamaru and Lemma, 2023). Relatively, adoption of improved pastures is notably higher in market-oriented systems such as cross-bred dairy production and livestock fattening, where economic returns are greater (Kebebe, 2015; Mamaru and Lemma, 2023).

Improved forage research programs have been going on over the past decades for selecting suitable forage grass species and identified over 75 species of grasses and legumes, that have been released for users (Fekede *et al*., 2022; Zeleke *et al*., 2022). Evaluations of various of these species has led to the select promising forage varieties assessed for ease of establishment, biomass yield, and resistance to pests and diseases. Among these, three *Brachiaria (Urochloa)* grasses were released. *Urochloa is an* important species to integrate into the existing farming system due to its adaptation to many soil types, resistance to many diseases (Alemayehu *et al.*, 2017), ability to withstand heavy grazing, and sequestration of carbon through its large root system with enhanced nitrogen use efficiency. It minimizes greenhouse gas emissions, improves its fertility, improves marginal lands (Maass, 2015), substantially supports the system, and enhances natural assets and system reliance (Ghimire *et al*., 2015). *Urochloa* grass can be easily cultivated, develops rapidly, and yields high amounts of dry matter and green forage of higher quality, improving animal nutrition and resulting in better livestock products with superlative agronomic managements (Mesfin *et al*., 2021).

Among the *Urochloa* grasses, *Urochloa mutica* is an important cultivar that has better dry matter yield and crude protein (Fantahun *et al.*, 2024). It is a vigorous plant; it’s integration into feeding programs can significantly improve growth performance and carcass characteristics, particularly when supplemented with protein-rich diets. Studies have shown that strategic supplementation of *Urochloa* grasses significantly improves feed conversion efficiency, growth rates, and carcass quality (Huang *et al*., 2023; Osman *et al*., 2023). According to the survey report of Wubetie *et al*. (2018), *Urochloa mutica* feeding increased milk yield of cross-breed dairy cows by 15 to 40% and improved crude protein content of milk. Thus, *Urochloa* grasses are a valuable forage option for ruminant livestock, particularly in tropical and subtropical regions, due to their high biomass production and relatively high nutritional value. However, it is important to consider the appropriate fertilizer type with the optimum rate, the stage of maturity, and the spacing between plants when utilizing *Urochloa* for optimal feeding results (Vendramini *et al.*, 2014).

Fertilizer type significantly impacts the growth and chemical composition of *Brachiaria mutica*, with commercial fertilizers like NPS generally showing better (Nagasu *et al.*, 2020). Combining different fertilizer types can significantly impact the yield and nutritional value of *Brachiaria (Urochloa) mutica*, with the specific effects depending on the fertilizer combination and application rates. Research indicates that combining inorganic fertilizers like NPS with organic amendments like vermicompost can lead to higher dry matter yields and improved nutritional content compared to using either fertilizer alone (Beyadglign *et al*., 2021). Optimum and suitable fertilizer application significantly impact the growth and yield of *Urochloa mutica*. The type of fertilizer and its combination, along with soil type and cultivar, all play a role in the extent of these effects (Beyadglign *et al.*, 2021). Therefore, a combination of inorganic fertilizers (for rapid nutrient availability) and organic fertilizers (for long-term soil health) is considered the most sustainable and productive approach (Tesfaye, 2018).

Additionally, plant spacing and harvesting age are appropriate for grasses, which play a key role in growing fast and tillering profusely (Mamilla *et al.,* 2020). Plant spacing substantially affects the yield of *Urochloa* grass, the number of plants, and the process of receiving sunlight, water, and nutrients, which also affect the process of photosynthesis and assimilation between plants (Wondimagegn *et al.,* 2021). Plant spacing of Bana grass

(*P. purpureum x P. typhoides*) influenced its nutritional contents (Berihun and Solomon, 2011). Subsequently, harvesting age significantly impacts *Urochloa mutica* in terms of its morphological characteristics, dry matter yield, and chemical composition. Mostly, plant spacing and harvesting age significantly impact forage yield, quality, and plant characteristics, influencing overall productivity and nutritional value for livestock (Nagasu *et al.*, 2020).

Improvements of *Urochloa mutica* productivity and nutritional composition through improvements of agronomic requirements, directly increase the livestock production and productivities which contribute to the national plan aimed to increase the production and productivities livestock such as 'Yelemat Turufat' (bounty of basket). Bounty of basket program, initiated by the Ethiopian prime minister, aims to enhance agricultural productivity and food self-sufficiency in Ethiopia. The program focused on increasing the production of dairy, eggs, chicken, and honey, with the broader goal of improving nutrition and livelihoods. It has mobilized over 20,000 villages nationwide, leading to significant improvements in milk production, egg distribution, and chicken numbers. The initiative aimed to boost productivity and production of livestock and fisheries commodities, contributing to food self-sufficiency (Tedele *et al*., 2023). Hence, appropriate fertilizer type, plant spacing, and harvesting age of *Urochloa mutica* definitely improve its potential in the study area and this support the **d**airy cows to produce more milk, which directly supporting the program's goal of boosting household nutrition. **S**mall ruminants gain weight faster, which improving meat supply and village-level productivity might be rises, aligning with the mobilization of 20,000+ villages under the initiative. So, *Urochloa mutica* isn't just a grass, it's a strategic lever for Ethiopia's livestock revolution. By fine-tuning agronomic practices, farmers can unlock its full potential and directly fuel the success of *Yelemat 'Tirufat'*.

Agronomic evaluation and utilization of *Urochloa* grass was addressed as the main research approach in Ethiopia to exploit such a potential forage. However, research outputs available over the past selection programs on forage species focused more on its adaptation to agroecology than important agronomic aspects and animal evaluation (Diriba, 2014).

Specifically, agronomic requirements such as combined blended NPS and vermicompost fertilizer application, plant spacing, harvesting age, and its feeding value were not assessed as a package for the *U. mutica* cultivar. Though, information on these factors is area specific and of the greatest significance for utilizing the grass and improving animal production and productivity. This highlights the necessity of generating a database on forage morphological characteristics, quality, and feeding value for promising forage species to enhance their production and utilization. The information will help to properly plan on the utilization and design interventions to maintain the productivity of *Urochloa mutia*, which will in turn increase the production and productivity of livestock. Hence, this dissertation research was basically aimed to evaluate morphological characteristics, yield, chemical composition and the feeding response of *Urochloa mutica* as influenced by fertilizer, plant spacing and harvesting age with the following objectives:

**General Objective**

To evaluate the effects of fertilizer, plant spacing and harvesting age on the morphological characteristics, yield, nutritional content, and feeding performance of *Urochloa mutica.*

**Specific Objectives:**

1. To evaluate the morphological characteristics, biomass yield, and nutritional composition of *Urochloa mutica* planted with various fertilizer types at Bishoftu Agricultural Research Center.

2. To study the effects of plant spacing and harvesting age on morphological characteristics, biomass yield, and nutritional composition of *Urochloa* grass at Bishoftu Agricultural Research Center.

3. To evaluate the feed intake, milk yield, and compositions of high-grade dairy cows fed on *Urochloa mutica* supplemented with graded levels concentrates at Holetta Agricultural Research Center.

# 2. LITRATURE REVIW

## 2.1.Overview of Available Feed Resources in Ethiopia

Livestock feed resources in Ethiopia are natural pasture (30%), crop residues (49%), improved forage (10%), agro-industrial by-products (11%), and other by-products like food and vegetable refused, which are major livestock feed resources, of which the first two contribute the largest feed type (Gezehgn *et al.*, 2016; Gezehgn, 2018).

**Natural pasture:** is the second major feed resource of animals, which is characterized by high spatial and temporal variability in rainfall (Alemu *et al.*, 2023). In the country, natural pasture made up primarily of grasses and herbaceous species, is the main source of feed for livestock production. There is seasonal fluctuation in the availability and quality of natural pasture (Andraw *et al*., 2024). Natural pastures have low dry matter yield and crude protein content, which can negatively impact livestock productivity. Overgrazing and land degradation are major issues, leading to a decline in both the quantity and quality of pastureland.

However, there are also strategies like fertilizer application, inter-planting of improved grasses, legume over-sowing, and feed conservation that can improve pasture quality and livestock production (Alemu *et al*., 2022). Moreover, interplanting improved forages into natural pasture is a strategy to enhance feed quantity and quality for livestock. This involves introducing high-yielding and nutritious forage species into existing grazing lands to supplement native vegetation (Alemayehu *et al.*, 2016). Improved forages, specifically fodder beet, improved grasses, and legumes, can produce significantly more yield than naturally growing pastures, providing a greater biomass for grazing (Kindu *et al*., 2021). Interplanting can help address feed shortages, particularly during dry seasons, by providing a reliable source of nutritious forage (Diriba *et al.*, 2023). Well-managed interplanted pastures can support sustainable grazing practices by providing a more balanced and resilient feed base (Abadi, 2017).

Thus, interplanting *Urochloa* grasses into natural pastures can significantly improve forage production and quality, making it a valuable practice for livestock production in tropical and subtropical regions. *Urochloa* grasses are known for their high biomass production, drought tolerance, and ability to thrive in low-fertility soils, making them a good choice for enhancing existing pastures (Diriba *et al.,* 2023). *Urochloa* grasses can produce significantly more forage than many native grasses, leading to a greater supply of feed for livestock. These grasses are generally more nutritious than many native grasses, offering higher protein and digestibility, which can improve animal performance (Yerosan *et al.*, 2023). *Urochloa* can improve soil fertility through nitrogen fixation and increased carbon sequestration, leading to healthier and more productive pastures. *Urochloa* grasses can withstand dry seasons and drought conditions, ensuring a more consistent forage supply throughout the year. The competitive nature of some *Urochloa* species can help suppress the growth of less desirable weeds in the pasture (Alemu *et al*., 2022).

**Crop residues:** the high dependency on crop residues as livestock feed is expected to be higher and higher, as more and more of the grazing lands are cultivated to satisfy the grain needs of the rapidly growing human population (Ahmed *et al*., 2010). The contribution of crop residues to the national feed resource base is significant (Getahun and Tegegn, 2018). Since the available evidence tends to indicate that, under the current Ethiopian condition, crop residues provide 49% of the annual livestock feed requirement (Belay and Geert, 2021). The annual crop residue production is estimated to be around 63 million metric tons. This production is dominated by cereal crop residues, which account for the majority of the crop residues in the country and leading in the crop-livestock system. Crop residue yield can be estimated from the grain yield for different crops through calculation of harvest index which is the ratio of grain to vegetative matter, can be used to estimate the quantity of crop residue produced. This ratio can be obtained from crop research institutes or determined in situ using grain and vegetative DM yields.

However, the optimum utilization of crop residues is constrained by their low feed quality as measured in terms of protein content and digestibility (Ahmed *et al*., 2010). Moreover, most of the crop residues used as livestock feed are subjected to seasonal fluctuation in availability and used without any treatment and/or strategic supplementation (Ahmed *et al*., 2010). Crop residues are of very poor feeding value, attributed to low metabolizable energy, available protein, and a serious deficiency in minerals and vitamins. Crop residues vary greatly in chemical composition and digestibility depending on varietal differences and agronomic practices. The feeding value of crop residues is also limited by their poor voluntary intakes and low digestibility. As a consequence, supplementing crop residue with improved forage is a practical and cost-effective strategy to overcome the low digestibility and poor protein content typical of cereal straws like teff, wheat, and maize.

**Agro-industrial by-products:** have a substantial contribution to the livestock feed supply. The by-products of the oil processing plants are oilseed cakes, which contain cottonseed cake, *noug* cake, linseed cake, sunflower cake, sesame cake, and rapeseed cake (Nayanika *et al*., 2021). The main by-product of the sugar factories is molasses, although bagasse and sugarcane tops are also other by-products that can be used as roughage sources. Molasses is a source of available energy to enrich microbial fermentation in the reticulo-rumen of ruminant animals (Bartholomew *et al*., 2003). However, the price of agro-industrial byproducts in general is very expensive, and they are in short supply.

Replacing agro-industrial by-products with improved forages is a critical strategy for sustainable livestock intensification, particularly in rural areas where agro-industrial by-products are often scarce, expensive, or concentrated in urban centers. While agro-industrial by-products like wheat bran and oilseed cakes are high-quality supplements, improved forages offer a more cost-effective, environmentally friendly, and farm-produced alternative for smallholders (Gebreegziaber and Tsegay, 2016). Accordingly, *Urochloa mutica* and concentrate feeds are typically characterized by partial substitution or strategic supplementation rather than a complete one-for-one replacement. *Urochloa mutica* serves as a high-quality basal forage that can significantly reduce the volume of expensive concentrates required to maintain high livestock productivity (Wubatie *et al.,* 2018).

**Improved forage and pasture crops:** have various benefits. From the perspective of ruminant livestock production, the main advantage is to produce a higher yield of better-quality feed. Furthermore, improved forage and pasture crops have a longer length of productive season, which provides an opportunity for dairy and fattening production to develop and use forage and pasture crops on a large scale (Alemayehu, 2006). They have been grown and used in state farms, government ranches, farmers' demonstration plots, and dairy and fattening areas (Alemayehu, 2004). Additionally, improved forage cultivation is practiced for various purposes such as a source of animal feed, soil conservation, crop rotation, windbreak, fence, and fuel. In Ethiopia, amongst the purposes of forage production, animal feeding and soil and water conservation account for the largest share (Gebreegziabher and Tsegay, 2016; Workye *et al.*, 2018).

The major barriers to improved forage production in different parts of the country are land tenure, lack of seed and planting materials, ecological deterioration, drought, weed and bush encroachment, overgrazing, and border conflict. Furthermore, improved forage production and utilization are restricted in the smallholder systems owing to scarcity of land, lack of an effective extension system, insufficient technical and material inputs, lack of specialization in livestock production, limited market orientation, and inadequate knowledge and awareness of the farmers in the country (Zewdie *et al.*, 2010; Adugna *et al*., 2012).

Relatively the potential role of adoption for improved forages might be higher under market-oriented livestock production systems, for instance, dairying with cross-breds or improved breeds and fattening of large and small ruminants (Gebremedihin *et al.*, 2003). With the support of externally funded projects, distinct efforts have been made by different organizations to promote improved fodder crops in the farming communities of the country. In spite of the promotion of improved forage production strategies, the contribution of improved forage as feed for livestock is minimal (10%) in the country (CSA, 2022).

On the other hand, improved forage can generally be utilized as green feed or conserved in the form of hay or silage for later use during the lean periods. Improved forage grasses, including *Brachiaria (Urochloa)* species, offer a valuable solution to Ethiopia's feed shortage challenges by providing higher quality and more abundant forage than traditional options. *Urochloa* grasses, such as *U. mutica, B. brizantha, and B. decumbens,* demonstrate high dry matter (DM) yield and crude protein (CP) content, which are crucial for animal nutrition. These grasses offer high-quality biomass, filling the gap left by low-nutritional natural pastures and crop residues. And this leads to higher animal production per head (Fekede *et al*., 2022). The nutritional composition of these grasses, including CP, neutral detergent fiber (NDF), ash, and dry matter digestibility, can vary based on cultivar, soil type, and harvesting stage (Fantahun *et al*., 2024).

***Urochloa* grasses:** are high-yielding, drought-tolerant, and nutritious forages increasingly used in Ethiopia for livestock feed and soil conservation. They provide high biomass and are well-adapted to Ethiopian highland environments, with crude protein (CP) ranging from 9.7% to over 18%, improving meat and milk production. The information and utilization of *U*. grasses was at an infant stage, which needs detailed research from adaptation on small plots of land to large scale, including evaluation of animal performance of different animal classes at different management practices and environmental conditions (Wubetie *et al.*, 2018).

### *2.2.Urochloa mutica*

*Urochloa mutica* is a high-yielding, perennial forage grass adapted to Ethiopia agro-ecology, particularly useful for boosting milk and meat production. It thrives on marginal, low-fertility, and acidic soils, offering drought and flood tolerance while endured well. It is well-suited for various Ethiopian agro-ecologies, especially in areas with moderate rainfall, and can withstand temporary waterlogging. *Urochloa mutica* has allopathic and toxic compounds (phenolic and unidentified ninhydrin positive) that inhibit the germination and growth of other plants. It could be an alternative grass to improve the existing natural grasslands in Ethiopia and enhance the availability of feed to the livestock sector (Mamilla *et al*., 2020).

### *2.2.1. Establishment, growing conditions and nutritive value of Urochloa grasses*

*Urochloa mutica* can be established under both rain-fed and irrigated conditions using rooted stalks. It is difficult to establish from seeds: they are expensive, dormant, and slow to germinate, and small seedlings can be killed by flooding (FAO, 2017). However, once established, the grass is tolerant to drought as it becomes dormant with a massive root system that enables growth to resume quickly whenever soil moistures are adequate (Ketema *et al.*, 2022). Under ideal management conditions (moisture/irrigation and fertilizer), second and subsequent harvests can be made after every 3-4 months depending on the moisture and temperature conditions of the area (Ketema *et al.*, 2022). The grass requires weeding till not fully established (FAO, 2017).

*Urochloa mutica* is a high-yielding grass with a higher proportion of leaf to stem ratio. On average, more than 12 tons of dry matter yield could be produced from a hectare of land annually, and 13.44% of crude protein was reported at Bore Agricultural Research Center (Ketema *et al*., 2022). Wubatie *et al*. (2019) reported 10.38 t/ha to 11.71 t/ha DMY and 8.57% to 14.93% CP concentration for *Brachiaria* grass in Northwestern Ethiopia. The highest CP content, 12.59%, 11.35%, and 9.56%, was recorded at the lowland, midland, and highland of Northwestern Ethiopia, respectively, with the lowest NDF and ADF by different *Urochloa* ecotypes (Wubatie *et al*., 2018). On the other hand, the CP content of 7-10% reported by Nguku *et al.* (2016) in the semi-arid region of eastern Kenya and Ondiko *et al.* (2016) also noted 5.3-7.7% CP content of *Urochloa* grass in coastal lowlands of Kenya. But Kifuko-Koech *et al*. (2016) reported the highest 12.9-16.2% CP content and lowest NDF concentrations of *Urochloa mutica* grass in western Kenya. Ash content of *Urochloa mutica* (14.65%) was reported by Ketema *et al*. (2022).

### *2.2.2. Feeding value*

Feeding of *Urochloa mutica* for ruminant animal is beneficial for both milk and meat production due to its high biomass yield, nutritional value, and ability to improve animal performance (Mwihaki Mundia, 2021). The intake of this grass improves the CP and ME intakes with increased milk yield when supplemented with concentrate. Hence, its utilization as a livestock feed is increasing from year to year in East Africa (Mutimura and Ghimire, 2021).

Studies conducted on small ruminants showed the use of an increased proportion (from 0 to 100%) of *Urochloa mulato II* hay in the basal diet increased feed intake and body weight in sheep (Wubatie *et al.,* 2018). *Urochloa mutica* feeding increased milk yield of cross-breed dairy cows by 15 to 40% and improved crude protein content of milk. Correspondingly, the study conducted on *Urochloa brizantha* and Napier grass (*P. purpureum*) feeding on *Bos taurus* and *Bos indicus* cross-bred cows in the East and Central African region indicated that the cows fed with *U. brizantha* had 33% more milk yield than cows fed with Napier grass. Higher average daily live weight gain was also observed in goats fed *Urochloa* grass compared with Rhodes grass (Ngila *et al*., 2016). Additionally, faster outflow rates from the rumen were observed with *U. brizantha* than with Napier grass and Rhodes grass diets (Ngila *et al.,* 2016). As elaborated by the investigators, this may be due to the better chemical composition of *Urochloa* grasses compared with that of Napier grass and Rhodes grass (Ngila *et al.*, 2016; Wubatie *et al*., 2018).

The above study indicates that the *Urochloa* grasses have better feeding value than the other grasses like Rhodes and Napier grasses, while Rhodes grass and Napier grass appear as better-quality forage in our country, Ethiopia. Rao *et al.* (2014) indicated that *Urochloa* grass has better acceptability by the farmers than Napier grasses. The investigator explained that there is an indication that the palatability and response of animals improve when fed on *Urochloa* grass rather than Napier grass. Therefore, the evidence based on this finding suggests that voluntary dry matter intake (DMI) in ruminants fed on *Urochloa* grass is less constrained by gut fill than in other grasses like Napier grasses. Gut fill is predominantly determined by rates of physical degradation of feed particles and the outflow rates of undegraded material from the reticulo-rumen of the animal (Zebeli *et al*., 2012).

### 2.2.3. *Fertilizer requirements of Urochloa grasses*

Blended nitrogen, phosphorus, and sulfur (NPS) fertilizer: This fertilizer is a compound fertilizer containing nitrogen (19%), phosphorus (38%), and sulfur (7%). It's designed to provide a balanced nutrient supply for plants, with the nitrogen in ammonium form, phosphorus as phosphate, and sulfur in sulfate form. This combination is intended to enhance nutrient uptake efficiency and reduce the negative impact of weather conditions on plant growth (Bekele *et al.,* 2024). The ammonium form of nitrogen promotes phosphorus uptake, which is crucial for early root development. Sulfur aids in the process of photosynthesis and protein synthesis (Ciro *et al.,* 2022). NPS fertilizer provides a balanced supply of essential nutrients, leading to better water uptake and overall plant health. The balanced nutrient supply can help plants withstand adverse weather conditions. By optimizing nutrient availability, NPS fertilizer can contribute to increased crop yields (Bekele *et al*., 2024).

Similarly, NPS fertilizer can be effectively used to boost the yield and nutritional quality of *Urochloa* grasses. NPS fertilizer application also positively influences crude protein yield, with higher biomass yields. The increased crude protein content contributes to improved nutritional value of the grass, making it a more valuable feed for livestock (Ketema *et al*., 2022). Applying NPS fertilizer to *Urochloa mutica* can significantly impact its yield and quality, with the optimal rate and harvesting stage depending on the specific goals. Studies have shown that the optimum rate of NPS fertilizer application generally leads to higher dry matter yield and crude protein content (Beyadglign *et al*., 2022). NPS fertilizer also influences other nutritional components like dry matter, fiber content, and in vitro dry matter digestibility of *Urochloa mutica* (Nagasu *et al*., 2020).

Consequently, agronomic performance of different forage grasses affected by NPS fertilizer application. According to Nagasu *et al.* (2020), application of NPS fertilizer has a significant effect on agronomic parameters of *Brachiaria hybrid mulato* II grass; maximum NTPP, NLPP, longest PH, and LL *of Brachiaria hybrid mulato* II were recorded from plants treated with NPS fertilizer compared to those treated with cattle manure in the lowlands of Northwest Ethiopia. Type, amount, and time of fertilizer application had a great influence on yield and quality of forage grasses. The increase in yields of grasses with increasing levels of NPS fertilizer to the optimum level could be attributed to the availability of macronutrients and some secondary nutrients formulated with the blended fertilizer, which could increase the vegetative growth and consequently the biomass yield. According to Kitaba, (2003) report, the application of fertilizers on natural pasture has been clearly shown to improve the herbage yields. According to the Nagasu *et al.* (2020) report, the highest mean DMY and CPY were recorded from NPS fertilizer application as compared to cattle manure and the control group for *Brachiaria hybrid mulato* II grass grown in the lowlands of Northwest Ethiopia.

Accordingly, the effect of NPS fertilization on the chemical content of forage was previously reported (Berihun *et al.,* 2018; Nagasu *et al*., 2020), and the higher mean CP content and ash percentage of Desho grass (*Pennisetum pedicellatum*) were recorded from the NPS fertilizer-applied group as compared with the control group in Northwestern Ethiopia. And also, the NDF, ADF, and ADL content was reduced with the NPS fertilizer-treated group while increased with the control group (Berihun *et al*., 2018). A similar result was reported by Nagasu *et al.* (2020), the highest mean DM content and mean CP concentration were recorded from NPS fertilizer application as compared to the control group, while ash content was decreased with the application of NPS fertilizer on *Brachiaria hybrid mulato* II grass grown in the lowlands of Northwest Ethiopia. The same author reported that the lowest NDF content was recorded with the application of NPS fertilizer, while the control group produced the highest NDF content.

Nitrogen fertilizer: Nitrogen fertilizer is a constituent of the proteins that participate actively in the synthesis of the organic compounds that comprise the vegetative structure, and it is responsible for size-related characteristics of the plants such as plant height, size of leaves and stem, and shoot emergence and development (Dupas *et al.,* 2010). Nitrogen fertilization significantly affects the appearance of tillers and interferes in the dynamics of the tiller population of the pasture. Application of the optimal level of nitrogen fertilizer significantly affects the appearance of new tillers and increases the dynamics of tiller population (Kizima *et al*., 2014). Mushtaque *et al.* (2010) also reported that nitrogen triggers the activation of dormant buds and enhances the vegetation sward filling through the highest rate of tiller replacement, which supports a higher proportion of very active, healthier young tillers for each plant, which results in higher tiller density and consequently increases biomass production in grass.

On the other hand, increased concentration of fertilizer can increase the nitrogen uptake, and this increase has a positive effect on chlorophyll concentration, photosynthetic rate, leaf expansion, the total number of leaves, and dry matter accumulation (Najm *et al.,* 2010). The report of Tessema *et al.* (2010b) also reveals that the DMY of the grass increased as the level of nitrogen fertilizer increased. Production of a high amount of forage yield can be achieved by increasing the tissue flow that is provided by the use of fertilizers, especially nitrogen (Garcez *et al*., 2012). The application of fertilizers on natural pasture has been clearly shown to improve the herbage yields (Kitaba, 2003). When N is applied, there is usually an initial linear response. But there are a phase of diminishing response and a point beyond which N has little or no effect on yield.

According to Fetene, (2016), DMY, CPY, LSR, and ME yields of the grass cultivated under irrigation showed an increasing trend with increasing nitrogen rate application at Gewane district, Northeastern Ethiopia. Additionally, Adewumi (2013) reported that the increment in CP content with the increment of fertilizer could have been due to an increase in the level of nitrogen fertilizer applied. The ash and CP content increase in forages with the addition of fertilizer (Aderinola *et al.,* 2011). Nitrogen fertilizer application increases CP concentration while decreasing NDF, ADF, and ADL content of Desho (*Pennisetum pedicellatum*) grass under irrigation in the Dehana district, Wag Hemra Zone, Ethiopia (Awoka *et al.,* 2020). DM content, CP concentration, and IVDMD percentage showed an increasing trend, while ash content, NDF, ADF, and ADL showed a decreasing trend with increasing urea fertilizer application rates on blue panic (Panicum antidotale Retz) grass cultivated under irrigation in the Gewane district, Northeastern Ethiopia (Fetene, 2016).

Phosphorus fertilizer: Phosphorus fertilizer is an integral component of important plant cell compounds; it is essential in the energy metabolism of plants. In addition, phosphate fertilization stimulates nitrogen absorption by the plant. Phosphorus application is important, which directly contributes to the quality and quantity of fodder production. Application of phosphorus fertilizer gradually increased plant height, stem diameter, number of leaves per plant, leaf area per plant, and fodder yield (Mahmood, 2003). Increasing levels of P significantly increased the crude protein content. While phosphorus fertilizer decreased neutral detergent fiber (NDF) content (Dasci *et al*., 2010). Addition of nitrogen and phosphorus results in considerably higher crude protein content (Goetz, 1975).

Sulfur fertilizer: Sulfur fertilizer is one of the sixteen essential nutrient elements and the fourth major nutrient after NPK, required by plants for proper growth and yield, as it is known to take part in many reactions in all living cells. It is a building block of protein and a key ingredient in the formation of chlorophyll. Without adequate S, crops cannot reach their full potential in terms of yield or protein content. It is required for the synthesis of S-containing amino acids such as cystine, cysteine, and methionine (Krauze and Bowszys, 2000). Crop responses to applied S have been reported in a wide range of soils in many parts of the world (Brady and Weil, 2002). Adequate S supply will increase yield, improve nitrogen use efficiency, and reduce the wastage of nitrogen loss to the environment (Norton and Poppi 2013). Sulfur metabolism in plants is determined by an appropriate N:S ratio. By influencing nitrogen metabolism, sulfur determines both crop yield and yield quality, and the availability of sulfur determines the efficient use of nitrogen by plants and affects plant composition and quality (Krauze and Bowszys, 2000).

Organic fertilizers: Organic fertilizers are fertilizers that are naturally produced and can be added to soil or plants in order to provide nutrients and sustain growth. It enriches soil, helps to retain moisture, suppresses plant diseases and pests, and reduces the need for chemical fertilizers. Also, the compost encourages the production of beneficial bacteria and fungi that break down organic matter to create humus, a rich nutrient-filled material, and reduces methane emissions from landfills and lowers carbon footprint. Typical organic fertilizers include all animal waste, including meat processing waste, manure, slurry, biosolids, bocashi compost, humic acid, and vermicompost. Vermicompost is a nutrient-rich soil amendment produced through the process of vermicomposting (Sharma *et al.*, 2019).

Vermicompost is the product of the decomposition process using various species of worms, usually red wigglers, white worms, and other earthworms, to create a mixture of decomposing vegetable or food waste, bedding materials, and vermicast. This process is called vermicomposting. Vermicompost has a plethora of benefits, most importantly as follows: (1) it acts as a biofertilizer, restores soil nutrients, stabilizes soil, and enhances soil fertility over a long period; (2) it attends to social issues and recycles waste; and (3) it is shown to be a profitable enterprise as a circular economy (Enebe and Erasmus, 2023). Vermicompost contains water-soluble nutrients and is an excellent, nutrient-rich organic fertilizer and soil conditioner. It is used in gardening and sustainable, organic farming.

Vermiculture reduces and eventually eradicates the need for chemical fertilizers, which continue to increase in cost. As the global demand for chemical fertilizers has increased, so have their prices all around the world (Vambe *et al.*, 2023). Containing water-soluble nutrients, vermicompost is a nutrient-rich organic fertilizer and soil conditioner in a form that is relatively easy for plants to absorb. Worm castings are sometimes used as an organic fertilizer. Because the earthworms grind and uniformly mix minerals in simple forms, plants need only minimal effort to obtain them. The worms' digestive systems create environments that allow certain species of microbes to thrive to help create a "living" soil environment for plants (Boruah and Deka, 2023).

Vermicomposting has gained popularity in both industrial and domestic settings because, as compared with conventional composting, it provides a way to treat organic wastes more quickly. Vermicompost application treatments compared with the control treatment, plant height increased by 38.9%, the yield of total biomass increased by 82.8%, and the yield of grain increased by 66.0% for barley grown on salt-affected soil in Hangzhou, China. Cattle manure application increased crude protein and IVDMD contents of the grasslands as opposed to chemical fertilizer application (Fikadu *et al.*, 2017). In the study carried out on Rhodes grasses in Nigeria, poultry manure showed better growth and higher fresh herbage and dry matter yields than urea (Ogedegbe and Ewansiha, 2016).

#### *2.2.4. Harvesting stage of Urochloa grasses*

Effects of harvesting stage on morphological characteristics: Grass plant physiology, and consequently, sward growth and structure, are highly affected by harvesting stages. Agronomic parameters of forage grasses were highly influenced by harvesting stages. Plant height, number of tillers per plant, number of leaves per plant, and leaf length of *Urochloa* grass ecotypes and *Urochloa mutica* were significantly increased as the harvesting stage increased from 60 to 120 days in Northwestern Ethiopia (Ketema *et al*., 2022; Wubatie *et al.*, 2019). According to Berihun and Solomon, (2011) findings, internode length per plant of Bana Grass (*Pennisetum purpureum* x *Pennisetum americanum*) was affected by harvesting days; late harvesting significantly produced longer internodes as compared to early and intermediate harvestings.

Leaf length per plant of Napier grass was lower at an earlier stage than at a later stage of harvest (Tessema *et al.*, 2010a). Changes in the number of leaves per plant are associated with changes in the number of internodes and thus the length of stems. Internode length of Napier grass increased significantly with increased days of harvesting (Zewdu and Baars, 2000). With advanced harvesting stage plant height, number of leaves per plant, leaf length, and re-growth dates (RGD) increase progressively on Desho grass (*Pennisetum pedicellatum*) in Ethiopia (Bimirew, 2016; Tilahun *et al.*, 2017). Fetene (2016) also reported that plant height, number of tillers per plant, number of leaves per plant, and leaf area parameters of Blue Panic (*Panicum antidotale*) grass cultivated under irrigation showed an increasing trend, while leaf length per plant showed a decreasing trend as days of harvesting increased at Gewane district, Northeastern Ethiopia.

Effects of harvesting stage on forage yield and quality parameters: The yield and quality of grassland are significantly influenced by harvesting stages of grass (Zewdu, 2005; Cop *et al.,* 2009). The higher DMY at later stages of harvesting was to be expected as plants were physiologically triggered, which leads to the increased production of tillers and more leaves per plant. Wubatie *et al.* (2018); Wubatie *et al.* (2019) report harvesting stages influence the dry matter yield (DMY) and crude protein yield (CPY) of *Urochloa* grasses in northwestern Ethiopia. Many researchers (Ketema *et al.,* 2022; Tessema *et al*., 2010a; Leta *et al.*, 2013) reported the highest DMY was produced from cultivated grasses and natural pastures, respectively, as harvesting stages delay in Ethiopia. This suggests that there may be a physiological trigger, which leads to the increased production of stem material in tropical pastures as the harvesting stage increases. Also, Awoka *et al*. (2020) ; Nagasu *et al*. (2020) reported an increasing trend in CPY with extended days of harvesting in the case of Desho grass and *Brachiaria* hybrid mulato II grass, respectively.

Dry matter and crude protein yield showed an increasing trend while ME yield and LSR showed a decreasing trend as days of harvesting increased for Blue Panic (*Panicum antidotale*) grass under irrigation at Gewane district, Northeastern Ethiopia (Fetene, 2016). Also, leaf-to-stem ratio is one of the best indications of the quality of forages; hence, a plant that has a high leaf-to-stem ratio also has high nutrition and digestibility. But at early stages of plant growth the stem of grasses is more easily digestible than the leaf parts of the plant, but as growth becomes advanced, the digestibility of the stem rapidly declines, while the nutritive value of the leaf parts slowly decreases (McDonald *et al.,* 1988). Ketema *et al*. (2022) reported a higher leaf-to-stem ratio of *Urochloa mutica* at the early harvesting stage (60 days) compared to the later dates (90 and 120 days). Wangchuk *et al*. (2015) also reported a sharp decline in the value of the leaf-to-stem ratio as the cutting intervals increased.

Accordingly, the highest CP concentration was obtained at the earliest stage of harvesting, with values declining as harvesting was delayed in different *Urochloa* ecotypes in Ethiopia (Wubatie *et al*., 2018). Limenih (2016) also reported that the CP content of Desho grass (*Pennisetum pedicellatum*) was significantly decreased as the harvesting stage increased from 90 to 150 days in Ethiopia. As days to harvest are increased, a reduction in quality, especially reduced CP concentrations and increased organic matter concentration, NDF, ADF, and ADL content with advancing maturity of *Urochloa mutica*, was reported from the Bore Agricultural Research Center (Ketema *et al*., 2022).

*In vitro* dry matter digestibility (IVDMD) is one of many factors influencing animal productivity (Mathison *et al.*, 1995). This is also influenced by the availability of the degradable materials of the feed (Campos *et al*., 2013). IVDMD of natural pasture and Napier grass harvested at relatively advanced stages of maturity was reduced, as noted by Kitaba (2003); Tessema *et al*. (2010b); Zewdu and Baars (2003), respectively. A decreasing trend in ME yield with advancing stages of plant maturity was reported by Zinash *et al.* (1995) for natural pasture and Napier grass (*Pennisetum purpureum*) in Ethiopia, respectively.

The NDF content in feed is one of the major criteria to predict dry matter intake in animals, especially for grazing animals. This is because high NDF content in a feed leads an animal to eat less feed (Lardner *et al*., 2015) and hence affects animal productivity. ADF is the percentage of highly indigestible and slowly digestible material in a feed or forage. Higher forage ADF results in reduced digestibility of dry matter because of increased lignification of cellulose in the latter stage of the plants. Ash content decreased with the advancement of the harvesting stage, which indicates the total ash content declined as the harvesting days of grass advanced in maturity. Fetene (2016) reported that the CP content, ash content, and IVDMD concentration of *Panicum antidotale* grass under irrigation conditions decreased as the harvesting stage prolonged, while the DM content, NDF, ADF, and ADL concentrations increased with delayed harvesting stage in the Gewane district, Northeastern Ethiopia.

### *2.2.5. Effects of plant spacing on Urochloa grasses*

Plant spacing has a critical effect on agronomic performance, yield, and quality of *Urochloa* grasses. A significant effect of plant spacing on leaf length per plant was reported by Nagasu *et al. (2020)* at Matakel Zone. They reported that, as plant spacing increased, there was an increase in the number of leaves per plant of *Urochloa hybrid mulato* II grass.

The number of leaves per plant (NLPP) of *Urochloa hybrid mulato* II grass was significant due to the effect of plant spacing. Correspondingly, Berihun *et al. (2018)* also reported that plant spacing was significantly different for leaf length per plant of desho grasses. According to Nagasu *et al.* (2020), the leaf-to-stem ratio of *Urochloa hybrid mulatto* II was affected by plant spacing; they stated that the highest leaf-to-stem ratio was observed at wider spacing, followed by intermediate and narrow plant spacing (1.39, 1.1, and 0.97, respectively).

The nutritional composition of *Urochloa* grasses and also all animal feed is very important, as the productivity of the livestock depends on the nutritional composition of the feed, such as dry matter content, crude protein, and fiber content. Likewise, different investigators reported that the nutritional composition of the *Urochloa* grasses can be affected by plant spacing. For instance, the dry matter yield of *Brachiaria mutica* was affected by plant spacing at Bahir Dar (Mamila *et al*., 2020), where 30x50 cm plant spacing was recommended for higher dry matter yield than 45x50. Negasu *et al. (2020)* also reported that the dry matter yield of *Urochloa hybrid mulatto* II was highly affected by plant spacing. In their study, high dry matter content (90.21% and 90.14%) was obtained at intermediate (30 cm) and narrow (15 cm) plant spacing than at wider plant spacing (45x50) in the lowlands of northwest Ethiopia.

# 3. MATERIALS AND METHODS

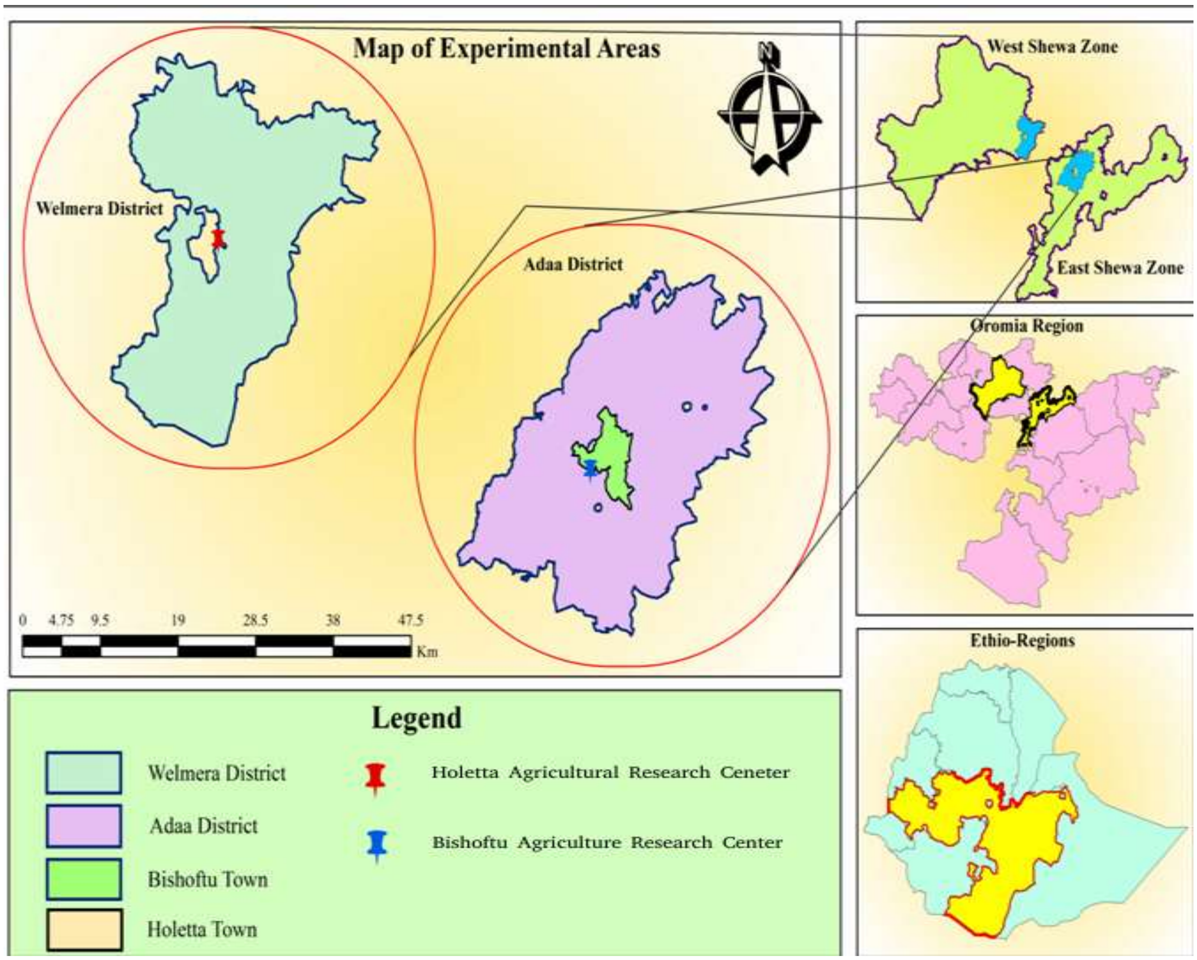
This chapter in general described information on the study locations, the experimental designs used to layout the field experiments and the experimental treatments tested. In addition, it described the laboratory and research methods employed to gather the data and statistical procedures employed to analyze and summarize the collected data. It has three sets of activities (three independent experiments were conducted): Experiment 1: Evaluation of morphological characteristics, biomass yield, and nutritional composition of *Urochloa mutica* planted with various fertilizer types at Bishoftu Agricultural Research Center. Experiment 2: Effects of plant spacing and harvesting age on morphological characteristics, biomass yield, and nutritional composition of *Urochloa mutica* at Bishoftu Agricultural Research Center. Experiment 3: Evaluation of the feed intake, milk yield, and compositions of cross-bred dairy cows fed on *Urochloa mutica* hay supplemented with graded levels concentrate.

## 3.1. Descriptions of the Study Locations

Experiments were conducted at Bishoftu and Holetta Agricultural Research Centers of the Ethiopian Institute of Agricultural Research. Agronomic Experiments were conducted at Bishoftu Agricultural Research Center (BARC) which was located at an altitude of 1850 m.a.s.l between 80 44` N latitude and 380 58` E longitude in Ada'a district of East Shewa Zone of Oromia Regional State (Figure 1). The average maximum and minimum temperatures of the area were 27.1$^{o}$C and 11.9$^{o}$C, respectively. The area has a bimodal distribution, with a long rainy season from June to September and a short rainy season from February to April. The experimental plots were laid out on Eutric vertisol with a clay texture.

Feeding experiment was conducted at Holetta Agricultural Research Center (HARC) located in Welmera District of West Shewa Zone of Oromia Regional State (Figures 1). The Center was situated at an altitude of 2400 m.a.s.l between 9° 03`N latitude and 38° 30`E longitude. The rainfall of the area has a bimodal pattern where around 75% of it falls during the main rainy season (June to September) and the rest 25% during the short rainy season (February to May). The average maximum and minimum temperatures of Holetta were 24.1°C and 6.4°C, respectively. Frost occurs during November to January when the minimum temperature occasionally drops below zero (HARC, 2003). Soils in the area were predominantly nitisols, which are acidic in nature (pH = 5.5) with medium status of fertility (Getachew *et al*. 2006).

Figure 1. Map showing the study locations



## 3.2.Field Preparation

A tractor equipped with a moldboard plow and disc harrow was used to plow and harrow experimental fields at BARC in order to create seedbeds with the ideal soil tilth in all three experiments. Before planting, soil samples were collected from the experimental site at a depth of 0 to 30 cm using a soil sampling augur and then examined for their physico-chemical properties in a soil laboratory (table 1).

Table 1. Soil physico-chemical properties of the experimental field before planting at BARC

| Parameters | Chemical Composition | Literature range | Notes |
|---|---|---|---|
| pH | 6.2 | 6.0 – 7.5 | Normal range |
| Organic Carbon (%) | 1.5 | 1.0 – 3.0 | Normal range |
| Organic Matter (%) | 2.6 | 2.0 – 5.0 | Normal range |
| Total Nitrogen (%) | 0.2 | 0.1 – 0.5 | Normal range |
| Available Phosphorus ppm) | 6.2 | 5 – 15 | Normal range |

ppm: Part per million

## 3.3.Experimental Design and Treatments

In all experiments including *Urochloa mutica* production for feeding Experiment, the experimental land was initially cleared. Manual hoeing and leveling of the experimental plot were carried out to achieve fine soil before it was divided into blocks and plots. The planting material evaluated in the experiment was *Urochloa mutica* (DZF-483) which was obtained by Bishoftu Agricultural Research Center from ILRI's collections for evaluating its adaptability to the area in 2015. Thereafter, it was verified for adaptation (Akililu and Asheber, 2018). The vegetative root splits of the planting material were transplanted under rainfed condition at Bishoftu. The distance between the plots was set at 0.5 m, while the space between replications was maintained at 1 meter. Prior to planting, the root splits of *Urochloa mutica* biomass were trimmed to the same height. According to the experimental design, each treatment was randomly and independently assigned to the experimental units within each block. Two-thirds of the root splits of the *Urochloa* grasses were buried at a depth of 15 cm in the experimental plot, while the remaining was left on the surface (Beyadglign *et al*., 2021). All experimental plots were cleared 45 days after planting for uniformity and were irrigated when necessary.

#### *3.3.1. Effects of fertilizer on morphological characteristics, biomass yield and nutritional composition of Urochloa mutica*

This study utilized 18 plots, each measured 12 m² (4 m x 3 m), with a 0.5 m spacing between plots and a 1 m spacing between replications. Row spacing was set at 50 cm, and intra-plant spacing was maintained at 25 cm (Getnet *et al.*, 2017). The Experimental design contained treatments involved organic fertilizer (vermicompost), inorganic fertilizer (NPS), and their combinations, all arranged in a randomized complete block design with three replications. Different fertilizer types (blended NPS, vermicompost and their combinations) were applied. The NPS fertilizer contain 19% nitrogen, 38% phosphorus and 7% Sulphur. The experimental treatments are presented in Table 2 below.

Table 2. Description of fertilizer types used in the Experiment

| Treatments | Fertilizer |
|---|---|
| $T_1$ | *U. mutica* Var. DZF-483 without fertilizer (Negative control) |
| $T_2$ | *U. mutica* Var. DZF-483 with 100% NPS + 100% urea |
| $T_3$ | *U. mutica* Var. DZF-483 with 100% vermicompost + 100% urea |
| $T_4$ | *U. mutica* Var. DZF-483 with 75% NPS and 25% vermicompost + 100% urea |
| $T_5$ | *U. mutica* Var. DZF-483 with 50% NPS and 50% vermicompost + 100% urea |
| $T_6$ | *U. mutica* Var. DZF-483 with 25% NPS and 75% vermicompost + 100% urea |

T= Treatment; NPS= Nitrogen, Phosphorus, Sulphur

*Urochloa mutica* roots splits were planted upright on mid-June 2021 at Bishoftu. The fertilizers were applied at time of planting based on the optional rate of NPS fertilizer (100 kg/ha). Vermicompost and its combinations were applied based on the nitrogen equivalency. Urea (50 kg/ha) was applied after 30 days of planting (Beyadglign *et al.*, 2021, Tesema *et al.*, 2015).

Vermicompost was prepared in concrete container at the Bishoftu Agricultural Research Center (BARC) soil research section. The raw materials used for bedding were teff straw, surface soil, and manure. The proportion of raw materials used was 75% manure and 25% surface soil and teff straw. Mature earthworm species *Eisenia fetida* were used as decomposers for both the bedding and feeding materials. The earthworms were fed with a weighed amount of 14kg cabbage and other residues every 2 weeks except the last 2 weeks before vermicompost harvest. Its process was undergone at normal temperature and 60% moisture level and was ready for harvest at 90 days. Harvesting of vermicompost was done using the hand method, starting from one side of the bin to the next side.

A vermicompost sample was taken in order to analyze its chemical composition. The pH was determined using a pH meter glass electrode in the extract of the saturated vermicompost (McLean, 1982). Total nitrogen content was analyzed using the Kjeldahl digestion, distillation, and titration method as described by Nelson and Sommers (1973). Phosphorus content was analyzed according to Jackson (1958). Organic carbon was determined following Walkley and Black (1934), and the result was described in table 3.

The pH of 7.62 was near neutral but slightly alkaline but remains within the ideal range (5.0 to 9.0) for vermicomposting bins and general plant growth. The C:N ratio of 7.14 is significantly lower than the preferred threshold of 15–20 for mature compost. A low ratio typically indicates that the organic matter has been thoroughly decomposed by earthworms and microbes, making it highly effective for immediate nutrient release in the soil. (Bati *et al.,* 2024). The total nitrogen (1.51%) and phosphorus (1.2%) levels are relatively high compared to some conventional composts, positioning this vermicompost as a potent organic fertilizer capable of improving soil fertility and crop yields.

Table 3. Composition of vermicompost used in the Experiment

| Chemical property | Value | Literature range | Notes |
|---|---|---|---|
| pH | 7.62 | 5.0 – 9.0 | Normal range |
| C; N ratio | 7.14 | 10 – 20 | Slightly lower |
| O C (%) | 9.0 | 10 – 20 | Slightly lower |
| Total N (%) | 1.51 | 0.5 – 2.0 | Normal range |
| Mg (%) | 0.56 | 0.3 – 0.6 | Normal range |
| Phosphorus (%) | 1.2 | 0.5 – 3.0 | Normal range |

C= carbon; N= nitrogen and Mg= magnesium

Vermicompost is superior for grasses due to its high nutrient density, rapid nutrient release, and enhancement of microbial activity. It improves moisture retention in arid soils, crucial for Ethiopian forage production (Tolera and Wakgari, 2021). It introduces beneficial microorganisms and growth hormones, which enhance seedling development and overall forage grass growth more efficiently than standard composting. It provides a sustainable, locally made fertilizer option that cuts down on the need for costly mineral fertilizers. Studies in Ethiopia show that, compared to conventional compost and chemical fertilizers, vermicompost application significantly boosted growth metrics and dry matter yield (DMY) of forage grasses (Enyew *et al.*, 2025). Generally, the combination of increased nutrient availability, better soil structure, and higher water retention makes vermicompost a superior, sustainable choice for enhancing Ethiopian forage production.

Therefore, prepared vermicompost was combined with NPS fertilizer at different percentage and applied to *Urochloa mutica* at planting. The rate of application of NPS fertilizer, vermicompost, and their mixes was then converted to hectare and shown in the following table.

Table 4. Used fertilizer types and their application rates

| Treatments | Amount of nutrient applied per hectare |
|---|---|
| $T_1$ | 0 kg |
| $T_2$ | 100 kg NPS + 50 kg urea |
| $T_3$ | 1258.3 kg vermicompost + 50 kg urea |
| $T_4$ | 75 kg NPS + 314.6 vermicompost kg + 50 kg urea |
| $T_5$ | 50 kg NPS + 629.1 kg vermicompost + 50 kg urea |
| $T_6$ | 25 kg NPS + 943.7 kg vermicompost + 50 kg urea |

NPS = blended nitrogen, phosphorus and Sulphur

### 3.3.2. *Effects of plant spacing and harvesting age on morphological characteristics, biomass yield, and nutritional composition of Urochloa grass*

In Experiment 2, *Urochloa mutica* (DZF-483) grass was transplanted in mid-June 2022 at Bishoftu Agricultural Research Center and fertilized with NPS 100 kg/ha at the time of planting and urea 50 kg/ha after 30 days of planting. Application of fertilizer was in concurrent only with the analyzed value of first year data in Experiment I. Due to the residual effects of vermicompost the second-year data results were improved and recommendation transformed.

The experiment was carried out using a randomized complete block design consisting of two factors (plant spacing and harvesting age) with three replications. There were three blocks, each containing nine plots, for 27 plots in total, with each plot measuring 3m x 4m. A factorial combination of three levels of intra-row spacing/plant spacing in the row (20 cm, 35 cm, and 50 cm) and was compared at three harvesting ages (60, 90, and 120 days) as described in Table 5 below.

Table 5. Description of different spacing and harvesting age in the experiment

| Treatments | Spacing between plant (cm) | Harvesting age (days) |
|---|---|---|
| $S_1$ | 20 | 60 |
| $S_2$ | 35 | 90 |
| $S_3$ | 50 | 120 |

S= space between plants

### 3.1.3. *Feed intake, milk yield, and compositions of cross-bred dairy cows fed on Urochloa mutica hay supplemented with graded levels concentrates.*

The experiment was achieved to evaluate the feed intake, milk yield and composition of high-grade dairy cows (75:25 Frisian -Boran) fed *Urochloa mutica* basal feed with graded level of concentrate. Experimental cows were selected from parity 1- 4 and milk yield (8kg/day on average) at the mid stage of lactation from the Holetta Agricultural Research Center dairy farm. They were checked for major contagious diseases and drenched with antihelmintic and sprayed against external parasite. The experimental cows were kept in individual pens. Treatments were arranged in a single 4 × 4 Latin square design. The design was composed of four parities and periods. Each period had 14 days of adaptation to the feed and 7 days of data measurement. In addition, animals were given 15 days of adaptation to the experimental house and feeds.

Period and parity differences were used as blocking factors. The experimental diets were feeding *U. mutica* hay ad libitum supplemented with graded levels of concentrate mixture, comprising four treatments (Table 6). The recommended concentrate level (0.5 kg/l/cow/day) for supplementation with roughage feed for cross-bred milking cows (Tesfaye *et al.*, 2021) was used as a control. Each cow received all four treatments during the entire course of the experimental periods without repetition, which lasted for 84 days.

Table 6. Layout of the experimental treatments

| Trts | Description | Amount offered | Con (kg/L/d |
|---|---|---|---|
| $T_1$ | *B. mutica* cv. DZF-483 | *ad libitum* | 0.5 |
| $T_2$ | *B. mutica* cv. DZF-483 | *ad libitum* | 0.4 |
| T3 | *B. mutica* cv. DZF-483 | *ad libitum* | 0.3 |
| $T_4$ | *B. mutica* cv. DZF-483 | *ad libitum* | 0.2 |

Con= concentrate and L= liter

**Feeds and Feeding Management:** The *Urochloa mutica* cultivar was grown with 100kg of NPS fertilizer at time of planting and 50kg urea after 30 days of planting. The intra-spacing used was 20cm and harvested at 120 days. The others managements were similar with the Experiment 1 and 2. The it was harvested, dried under shed and stored for six months until the feeding Experiment started.

*Urochloa mutica* basal diet was fed to the animals *ad libitum* (adjusted up to 20% refusal) in the morning after it was being chopped to 25 cm in order to minimize selection. Fresh and clean water was offered at all times throughout the experimental period. Each cow was randomly assigned to a diet that consisted of four levels of concentrate supplementation offered during milking times.

### 3.4.Data Collection

In Experiment 1, data on morphological characteristics and yield parameters were collected by harvesting (clearing) at one meter height on average as suggested by (Wubatie *et al.*, 2019) for *Urochloa* grass cultivars under midland climatic conditions of southern Ethiopia. Five clearing dates were performed and the five harvests averaged. In Experiment 2, three harvesting (clearing) ages were considered (60, 90, and 120 days of harvesting age) and finally averaged. In both Experiments, five plants were randomly selected per plot by avoiding border plants to record the number of tillers per plant (NTPP), the total number of leaves per plant (NLPP), leaf length per plant (LLPP), the length and number of roots per plant. Harvesting was done by hand using a sickle after the two boarder rows were excluded from 8.75 $m^2$ leaving stubble at a height of 10 cm, which was recommended by Tudsri *et al.* (2002).

Plot cover was measured based on visual observation by rating the ground cover (1-10) (Fantahun *et al.*, 2024) with a higher score indicating better coverage. A measurement of plant height was undertaken immediately before the time of biomass harvest at each harvesting date. From the total of rows within each plot, then five tillers were randomly selected for the measurement of plant height. It was measured from the base of the plant to the tip of the upper leaves of the main stem.

The number of tillers per plant of *Urochloa mutica* was counted from the randomly selected sample of five plants of each plot, and the mean was calculated. The number and length of leaves per plant were counted from the sample of five plants. The mean number of leaves per tiller was calculated, and then the total number of leaves per plant was estimated from the tiller number per plant. Leaf length per plant was measured by a graduated ruler from the base of the collar region of the leaf to the tip of the leaf and the mean was calculated.

The number and length of roots were counted and measured, respectively, after the shoot parameters were accomplished. At the end of harvesting day, all sets of roots in the experimental field were collected without sampling from all plots by avoiding two border rows with an auger at 0.5 m depth. Then sets of samples from each plot were cleaned up from any residual soil and other debris. The numbers of roots per plant were counted. The length of the root was measured from the crown part to the tip of the root by a graduated ruler, and their mean was calculated.

Total forage dry matter accumulation was obtained from multiple cuts (five times in Experiment 1 and five times in Experiment 2 harvested at 120 days, eight times in Experiment 2 harvested at 90 days, and 10 times in Experiment 2 harvested at 60 days), and the total forage dry matter accumulation was presented as the total yield harvests. Harvesting was done by hand using a sickle, and the harvested herbage was weighed freshly in the field using a field balance, and a 300-gm fresh sample was taken from each plot to the laboratory.

The sample taken from each plot was oven-dried for 72 hours at a temperature of 60°C. The oven-dried samples were weighed to determine dry matter yield. Forage dry matter accumulation was calculated from green forage and dry matter percentage as dry matter yield (t/ha) = Green forage accumulation (t/ha) x dry matter content%/100 (Asemahegn and Abera, 2022). Crude protein yield in tons per hectare was calculated from crude protein percentage and total dry matter yield as CPY = CP% × DMY (t/ha)/100.

Similarly, fifteen harvested plant samples from each plot were used to calculate the dry leaf-to-stem ratio. Each gathered sample's fresh stems and leaves were separated and weighed. After oven-drying each leaf and stem sample for 72 hours at 60°C, the leaf-to-stem ratio was calculated by dividing the dry weight of the leaves by the dry weight of the stems (Mulisa and Alemayehu, 2020).

**Forage quality measurements:** In each Experiment 1, 2, and 3, chemical analyses of the bulked feed samples were examined at the Holetta Agricultural Research Center Animal Nutrition Laboratory annually. The dried samples were ground to pass through a 1 mm sieve and kept at room temperature in sealed plastic bags pending laboratory analyses. Feed samples were analyzed for DM, total ash, and N (Kjeldahl method) (AOAC, 1990). Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin were determined by the methods of Van Soest and Robertson (1985). Organic matter of the feed sample was determined from the dry matter and ash content of the feed (AOAC, 1990).

In Experiments 1 and 2, IVDMD was determined using a calibrated near-infrared reflectance spectroscopy (NIRS) apparatus available at the Holetta Agricultural Research Center. The NIRS procedure was performed on 3 g of ground sample using Foss NIRS 5000 in the 1108–2492 spectral range with an 8-nanometer step. Prior to scanning, the samples were pre-dried at 60°C overnight in a forced air draft oven to normalize moisture conditions. Each sample spectrum was taken by scanning using Win Scan 1.5, 2000 Infrasoft International software (Dereje *et al.*, 2010).

**Feed intake:** In Experiment 3, concentrate feed was purchased from Amen Animal Feed and Poultry Distributor were weighed and offered twice a day during milking times in a separate trough. Roughage feed refusals were collected, weighed, and recorded before the next feeding. Samples of feed offered and refused were separately collected and bulked, and sub-samples were submitted to the laboratory. Feed intake was calculated as the difference between the quantity of feed offered and feed refused per animal per day.

**Estimated metabolizable energy:** These determinations involved measurements of feed intake and total fecal output over the seven days of period, followed by laboratory analysis of both feed and feces for organic matter (OM) content. Overall fecal matter excreted was collected for seven days immediately after dropped from the ground in each period, weighed, and a sub-sample was taken to Holetta Agricultural Research Center for analysis. Then OM was calculated from percent dry matter and ash. The steps followed to calculate ME was as follows:

Step 1: OM intake = feed intake × % OM in feed

Step 2: Fecal OM = fecal output × % OM in feces

Step 3: *In-vivo* OMD = OMD% $= \frac{(Total\ OM\ intake - Total\ fecal\ OM\ output)}{Total\ OM\ intake} \times 100$

Step 4: Digestible Organic Matter in Dry Matter (DOMD)=

$$\text{DOMD (g/kg DM)} = \frac{\text{OM digested}}{\text{DM intake}} \times 1000$$

Step 5: ME

ME *(MJ/kg DM)* $= 0.016 \times$ *DOMD (g/kg DM)* Baran *et al*. (2017)

This converts digestible organic matter into an estimate of the energy available to the animal.

**Milk Yield and Composition:** The milk yield was measured every day in the morning and evening after the cows were manually milked twice a day. A graduated glass cylinder was used to measure it, and the results were recorded for every experimental cows. The HARC dairy processing laboratory received pooled milk samples (100 ml) from the morning and evening milking throughout the course of the previous seven days. A milk Lacto Scan analyzer was used to measure the total solids, protein, lactose, and fat contents of individual milk composite samples after it has been promptly thawed and completely mixed using a vortex mixer.

### 3.5.Cost Benefit Analysis

In both Experiments 1 and 3, to assess the economic viability, a partial budget analysis was conducted. The partial budget analysis methods described in CIMMYT (1988) served as the basis for cost-benefit assessments. For the economic analysis, the prevailing market price for inputs through the experimental period and the prevailing market price for outputs (*Urochloa mutica* yield, milk yield, and cow's dung cake yield) were estimated. The mean herbage yield, milk yield, and cow's dung cake yield for each treatment were averaged. A partial budget analysis was conducted. The mean herbage yield of *Urochloa mutica* was computed as the average yield (kg/ha$^{-1}$) of each treatment minus 10% of the yield (to estimate what can be expected for a farmer's field). In Experiment 1, all costs and benefits were calculated on a hectare (ha$^{-1}$) basis while on daily bases in Experiment 3. In both experiments the net returns (benefits) and other economic analyses were based on the formula developed by CIMMYT (1988) given as follows:

Unadjusted herbage yield (UHY) (kg ha$^{-1}$): was the average yield of *Urochloa mutica* in each treatment.

Unadjusted milk yield (UMY) (kg ha-1): was the average yield of milk in each treatment. Adjusted herbage yield (AHY) (kg ha$^{-1}$): was the average herbage yield adjusted downward by 10% to reflect the difference between the experimental yield and yield of farmers.

Adjusted milk yield (AMY): was the average milk yield adjusted downward by 10% to reflect the difference between the experimental yield and yield of farmers.

Gross field benefit (GFB) (ETB ha$^{-1}$): it was computed by multiplying field/farm gate price that farmers receive for the hay, milk and dung cake when they sell it as adjusted yield. GFB = Adjusted gross yield (AGY) × field/farm gate price for the *U. mutica*.

Total variable cost (TVC) (ETB ha$^{-1}$): in Experiment 1, it was calculated by summing up the costs that vary, including the cost of NPS and urea fertilizer (45.00 ETB kg-1), and also cost of vermicompost (4 ETB kg$^{-1}$), according to Bishoftu farm daily payment of labor cost for application of fertilizer (2 people per hectare, each 65 ETB day$^{-1}$). The costs of other inputs and production practices such as labor cost for land preparation, planting, weeding and harvesting were considered the same for all treatments. In Experiment 3, it was calculated by totaling up the costs that vary, including the cost of *U. mutica*, concentrate and according to Holetta farm daily payment of labor cost for animal management and milking was 65 ETB per day.

Net benefit (NB) (ETB ha$^{-1}$): was calculated by subtracting the total variable costs (TVC) from gross field benefits (GFB) for each treatment. NB = GFB – TVC.

Dominance analysis: was carried out by first listing all the treatments in their order of increasing costs that vary (TVC) and their net benefits (NB) are then put aside. Any treatment that has higher TVC but net benefits that are less than or equal to the preceding treatment (with lower TVC but higher net benefits) is dominated treatment (marked as "D").

Marginal rate of return (MRR) (%): was calculated by dividing the change in net benefit ($\Delta$NB) by change in total variable cost ($\Delta$TVC) then multiplied by 100.

## 3.6.Statistical Analyses

Morphological characteristics, forage yield and the respective forage chemical composition data were analyzed using the procedure outlined by Steel and Torrie (1986) for a factorial experiment using the SAS statistical computer package version 9.0 (SAS, 2002). Significant treatment means were compared by the Duncan's Multiple Range Test ($p < 0.05$). The statistical model used for the analysis of fertilizer type data was:

$Y_{ij} = \mu + f_i + e_{ij}$, where:
$Y_{ij}$= dependent variables
$\mu$ = overall mean
$f_i$= effects of $i^{th}$ fertilizer
$e_{ij}$= random error

The statistical model for the analysis of plant spacing and harvesting age data was:

$Y_{ijk} = \mu + S_i + H_j + S_i * H_j + e_{ijk}$, where:
$y_{ijk}$=all dependent variables
$\mu$=overall mean
$S_i$ = the effect of $i^{th}$ spacing
$H_j$ = the effect of $j^{th}$ harvesting
$S_i*H_j$ = interaction of plant spacing and harvesting age
$e_{ijk}$ = random error

In Experiment 3, the collected data on feed intake, feed chemical composition, milk yield, and milk composition were subjected to an analysis of variance (ANOVA) procedure for Latin square design using SAS (2002). The Tukey test was employed to separate the means, and differences between treatment means were declared significant at $P \leq 0.05$. The model used for the analysis of data was as follows:

$Y_{ijk} = \mu + P_i + T_k + E_{ijk}$, where:

$Y_{ijk}$ = variable response,

$\mu$ = overall mean;

$P_j$ = period effect;

$T_k$ = treatment effect,

$E_{ijk}$ = experimental error.

# 4. RESULTS

This section contains three parts. In Experiment 1, results of the morphological characteristics of *Urochloa mutica*, subsequent dry mater yield, leaf to stem ratio, chemical composition and *in vitro* dry matter digestibility as affected by fertilizer types (NPS, vermicompost and their combinations) were presented. Data on morphological characteristics, subsequent dry mater yield, crude protein yield, chemical composition and metabolizable energy as influenced by plant spacing and harvesting age were presented in Experiment 2. In Experiment 3, the effect of *Urochloa mutica* feeding as basal feed with graded level of concentrate mixture on feed intake, milk yield and milk composition on high grade dairy cows were described.

## 4.1.Fertilizer Effects on Morphological Characteristics and Yield

Morphological characteristics and yield of the grass averaged from the five clearing cuts, were analyzed. The result of ground cover of *Urochloa mutica* was slightly affected by the type of fertilizer. The highest mean was 9.8 from 100% NPS fertilizer, while the lowest was 6.7 from the control plot. Both vermicompost and NPS fertilizers improved plant height. The tallest plants were seen with 100% NPS and 75% NPS mixed with 25% vermicompost. The number of tillers per plant was significantly higher in blended NPS and the combined use of NPS and vermicompost. It reached a maximum of 176.5 from $T_4$ (75% NPS + 25% vermicompost) and a minimum of 76.2 from the control group. The number of leaves per plant was highest in 75% NPS + 25% vermicompost at 1369.9, compared to 506.2 in the control. Leaf length increased as well, with a maximum of 31.6 cm from the sole blended NPS fertilizer groups. The number of roots per plant rose with the application of NPS and vermicompost. Fertilizer types also affected root length, with the longest roots from 100% NPS and 75% NPS + 25% vermicompost.

The leaf to stem ratio (LSR) showed positive effects from using NPS, vermicompost, and their mixture, as showed in table 7. There were no significant differences ($p < 0.05$) among the treatments of 100% NPS, 100% vermicompost, and their combinations. The control treatment had the lowest LSR, while all combinations and individual applications of vermicompost and NPS reached a higher LSR compared to the control. Afterwards, *Urochloa mutica's* biomass yield revealed the highest values of 17.9 t/ha in 100% NPS and 17.4 t/ha in 75% NPS + 25% vermicompost. In contrast, the control plots recorded a significantly lower yield of 8.2 t/ha.

Table 7. Morphological characteristics and yield of *Urochloa mutica* as affected by fertilizer type grown at Bishoftu, Ethiopia

| Trts | GC scale | PH cm | NTPP | NLPP | LLPT cm | NRPP | RLPP cm | LSR | DMY t/ha |
|---|---|---|---|---|---|---|---|---|---|
| $T_1$ | $6.7^{d}$ | $62.3^{e}$ | $76.2^{c}$ | $506.2^{c}$ | $18.3^{e}$ | $64.8^{d}$ | $10.1^{d}$ | $1.2^{b}$ | $8.2^{d}$ |
| $T_2$ | $9.8^{a}$ | $100.7^{a}$ | $176.0^{a}$ | $1356.0^{a}$ | $31.6^{a}$ | $114.4^{a}$ | $20.3^{a}$ | $3.2^{a}$ | $17.9^{a}$ |
| $T_3$ | $6.9^{d}$ | $70.3^{d}$ | $151.7^{b}$ | $1222.9^{ab}$ | $21.3^{d}$ | $109.1^{ab}$ | $14.7^{c}$ | $3.0^{a}$ | $12.8^{c}$ |
| $T_4$ | $8.8^{b}$ | $95.0^{ab}$ | $176.5^{a}$ | $1369.9^{a}$ | $30.2^{ab}$ | $109.5^{ab}$ | $18.3^{ab}$ | $3.2^{a}$ | $17.4^{a}$ |
| $T_5$ | $8.1^{c}$ | $92.7^{bc}$ | $166.7^{ab}$ | $1241.1^{ab}$ | $28.2^{b}$ | $99.1^{bc}$ | $16.9^{bc}$ | $3.0^{a}$ | $16.5^{ab}$ |
| $T_6$ | $7.3^{d}$ | $88.0^{c}$ | $156.5^{b}$ | $1050.5^{b}$ | $25.6^{c}$ | $94.2^{c}$ | $15.9^{bc}$ | $2.8^{a}$ | $14.7^{bc}$ |
| Mean | 7.9 | 80.0 | 150.4 | 1124.4 | 25.9 | 98.5 | 15.9 | 2.5 | 14.6 |
| Sig. | ** | ** | ** | * | ** | ** | ** | * | ** |

$T_1$= without fertilizer, $T_2$ = 100% NPS + 100% urea, $T_3$ = 100% vermicompost, $T_4$ = 75% NPS + 25% vermicompost, $T_5$ = 50% NPS + 50% vermicompost, $T_6$ = 25% NPS + 75% vermicompost, GC= ground cover, PH= plant height, NRPP= number of roots per plants, LLPP= leaves length per plants, NRPP= number of roots per plants, RLPP= roots length per plants, LSR= leaf to stem ratio and DMY t/ha = dry matter yield ton per hectare.

## 4.2.Fertilizer Effects on Chemical Composition and *In-vitro* Dry Matter Digestibility

Crude protein (CP) and ash content in *Urochloa mutica* were affected by the type of fertilizer. Treatments that used only NPS, a mix of NPS and vermicompost, or only vermicompost showed significantly higher values than the control groups. Neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) levels were higher in plots without fertilizer. These levels were significantly lower in treatments $T_2$ (100% NPS), $T_3$ (100% vermicompost), $T_4$ (75% NPS and 25% vermicompost), and $T_5$ (50% NPS and 50% vermicompost). Additionally, the types of fertilizer and their combinations influenced the in vitro dry matter digestibility of *Urochloa mutica*. It was significantly higher in the sole NPS group and in the mixed application of NPS with vermicompost (75% NPS + 25% vermicompost) compared to the plots without fertilizer (table 8).

Table 8. Percentage of chemical composition and *in vitro* dry matter digestibility of *Urochloa mutica* established at Bishoftu, Ethiopia

| Trts | DM | CP | Ash | NDF | ADF | ADL | IVDMD |
|---|---|---|---|---|---|---|---|
| $T_1$ | 88.1 | $9.2^{b}$ | $8.5^{c}$ | $71.8^{a}$ | $40.7^{a}$ | $9.8^{a}$ | $54.1^{c}$ |
| $T_2$ | 93.1 | $14.3^{a}$ | $12.3^{a}$ | $65.9^{d}$ | $36.5^{c}$ | $6.1^{c}$ | $64.9^{a}$ |
| $T_3$ | 89.7 | $13.6^{a}$ | $11.5^{ab}$ | $67.2^{bc}$ | $36.2^{c}$ | $7.6^{bc}$ | $56.5^{bc}$ |
| $T_4$ | 92.5 | $14.1^{a}$ | $11.5^{ab}$ | $65.0^{d}$ | $37.3^{bc}$ | $6.8^{bc}$ | $61.8^{ab}$ |
| $T_5$ | 91.3 | $13.3^{a}$ | $10.7^{ab}$ | $66.5^{bcd}$ | $37.3^{bc}$ | $7.5^{bc}$ | $58.7^{bc}$ |
| $T_6$ | 90.8 | $13.5^{a}$ | $10.9^{ab}$ | $68.4^{b}$ | $39.0^{ab}$ | $8.4^{ab}$ | $57.1^{bc}$ |
| Mean | 90.9 | 12.9 | 10.9 | 67.5 | 37.8 | 7.7 | 58.8 |
| Sig. | ** | * | ** | ** | ** | ** | ** |

$T_1$= without fertilizer, $T_2$ = 100% NPS + 100% urea, $T_3$ = 100% vermicompost, $T_4$ = 75% NPS + 25% vermicompost, $T_5$ = 50% NPS + 50% vermicompost, $T_6$ = 25% NPS + 75% vermicompost, DM= dry matter, CP= crude protein, NDF= neutral detergent fiber, ADF= acid detergent fiber, ADL= acid detergent lignin and IVDMD: In-vitro dry matter digestibility

## 4.3.Effects of Fertilizer type on Economic Feasibilities

All treatments were evaluated for economic benefits through partial budget analysis. The analysis indicated that the highest net benefits were recorded with NPS at 100 kg/ha (birr 128,018.7) and a combination of 75% NPS and 25% vermicompost (birr 127,554.7), showed remarkable marginal rates of return at 163.91% and 175.2%, respectively. The control plot yielded the lowest benefit of birr 30,836.8. Treatment recommendations were based on transitions from one treatment to another if the marginal rate of return from such changes surpassed the minimum acceptable rate, as defined by CIMMYT (1988) at between 50% and 100%. Therefore, the most economically viable options for farmers were identified as using combination of 75% NPS with 25% vermicompost and 100% NPS fertilizer.

Table 9. Calculated marginal rate of return for treatments of *Urochloa mutica* at Bishoftu, Ethiopia

| Trts | Adj. HY kg/ha | Total Revenue | TVC | Net benefit | MRR% |
|---|---|---|---|---|---|
| T1 | 7,454.6 | 94,424.3 | 63,587.5 | 30,836.8 | 48.5 |
| T2 | 16,272.7 | 206,121.2 | 78,102.5 | 128,018.7 | 163.9 |
| T3 | 11,636.4 | 147,393.9 | 70,500.0 | 76,893.9 | 109.1 |
| T4 | 15,818.2 | 200,363.6 | 72,808.9 | 127,554.7 | 175.2 |
| T5 | 13,363.6 | 190,000.0 | 69,301.3 | 120,698.7 | D |
| T6 | 11,090.9 | 164,121.2 | 66,025.6 | 98,095.6 | D |

Trts = treatments, Adj. HY= adjusted hay yield, TVC = total variable cost and MRR= marginal rate of return, $T_1$= without fertilizer, $T_2$ = 100% NPS + 100% urea, $T_3$ = 100% vermicompost, $T_4$ = 75% NPS + 25% vermicompost, $T_5$ = 50% NPS + 50% vermicompost, $T_6$ = 25% NPS + 75% vermicompost and D = dominated treatment.

## 4.4. Effect of Plant Spacing and Harvesting Age on Morphological Characteristics

In the study of *Urochloa mutica*, various agronomic parameters were evaluated regarding ground cover, plant height, number of tillers per plant, number of leaves per plant, leaf length per plant, number of roots per plant, and root length per plant averaged from multiple harvests as influenced by plant spacing and harvesting age. The highest ground cover was observed in treatment $T_3$, while $T_7$ showed lower coverage. Plant height peaked at 108.19 cm with 50 cm spacing and a 120-day harvest. The maximum number of tillers (167.60) was also recorded at wider spacing (50 cm) after 120 days of growth. In terms of foliage, the highest number of leaves (1117.05) corresponded with late harvesting and wider spacing. Leaf lengths reached their maximum (29.66 cm and 27.97 cm) at 50 and 35 cm spacing with 120- and 90-day harvesting, respectively. Furthermore, root numbers were highest (128.53) at 50 cm of spacing after 120 days, while root length increased with both plants spacing and harvesting age, with the longest roots (21.10 cm) observed at intermediate and late harvesting ages.

Table 10. Effects of plant spacing and harvesting age on morphological characteristics of *Urochloa mutica* grown at Bishoftu, Ethiopia

| Trts | PS | HA | GC scale | PH (cm) | NTPP No. | NLPP No. | LLPP (cm) | NRPP No. | RLPP (cm) |
|---|---|---|---|---|---|---|---|---|---|
| $T_1$ | 20 | 60 | $9.1^a$ | $73.9^c$ | $116.8^e$ | $902.9^{cd}$ | $20.6^e$ | $93.2^e$ | $12.3^c$ |
| $T_2$ | 20 | 90 | $9.2^a$ | $95.7^{ab}$ | $138.8^{cd}$ | $974.5^{bc}$ | $27.2^b$ | $110.7^{cd}$ | $18.2^b$ |
| $T_3$ | 20 | 120 | $9.3^a$ | $104.4^{ab}$ | $155.5^{abc}$ | $1041.6^{ab}$ | $28.8^{ab}$ | $118.93^{bc}$ | $19.6^{ab}$ |
| $T_4$ | 35 | 60 | $8.8^{abc}$ | $90.1^b$ | $124.1^{de}$ | $950.0^{bc}$ | $25.1^c$ | $110.0^d$ | $17.3^b$ |
| $T_5$ | 35 | 90 | $8.9^{ab}$ | $101.8^{ab}$ | $142.8^{bcd}$ | $1016.5^{ab}$ | $26.8^{bc}$ | $116.7^{bcd}$ | $18.7^{ab}$ |
| $T_6$ | 35 | 120 | $9.0^{ab}$ | $104.9^{ab}$ | $161.9^{ab}$ | $1112.7^a$ | $28.1^{ab}$ | $120.5^b$ | $21.1^a$ |
| $T_7$ | 50 | 60 | $8.2^d$ | $91.4^b$ | $123.7^{de}$ | $823.5^d$ | $22.9^d$ | $111.9^{cd}$ | $17.9^b$ |
| $T_8$ | 50 | 90 | $8.4^{cd}$ | $95.1^{ab}$ | $146.4^{bc}$ | $972.5^{bc}$ | $20.0^{ab}$ | $116.4^{bcd}$ | $18.5^{ab}$ |
| $T_9$ | 50 | 120 | $8.6^{bcd}$ | $108.2^a$ | $167.6^a$ | $1117.1^a$ | $29.7^a$ | $128.5^a$ | $20.9^a$ |
| | Mean | | 8.8 | 96.2 | 141.9 | 990.1 | 26.4 | 114.2 | 18.3 |
| | Sig. | | ** | ** | ** | ** | ** | ** | ** |

Trts= treatment, PS= plant spacing, HA= harvesting age, GC= ground cover, PH= plant height, NTPP= number of tillers per plants, NLPP= number of leaves per plants, LLPP= leaves length per plants, NRPP= number of roots per plants and RLPP= root length per plants.

### 4.5.Effects of Plant Spacing and Harvesting Age on Forage Yield

The leaf to stem ratio (LSR), total dry matter yield (DMY), and total crude protein yield (CPY) of *Urochloa mutica* were influenced by various plant spacings and harvesting ages. For the LSR, the narrowest spacing (20 cm) at an early harvesting age (60 days) yielded the highest ratio (3.07), significantly different from those harvested at intermediate (90 days) and late (120 days) stages, with the LSR declined sharply as the age of harvesting increased. Significant interaction effects were noted between plant spacing and harvesting age. The results showed that, both narrow spacing and advanced harvesting increased dry matter yield, achieved a maximum yield of 15.67 t/ha at narrow spacing (20 cm), which was significantly consistent across wider spacings at late harvesting age. The CPY results indicated that the highest values were found at late harvests with narrow spacing, showcasing significant effects from both plants spacing and harvesting age on crude protein yield.

Table 11. Effects of plant spacing and harvesting age on leaf to stem ratio and forage yields of *Urochloa mutica* at Bishoftu.

| Trts | PS | HA | LSR | DMY t/ha | CPY t/ha |
|---|---|---|---|---|---|
| $T_1$ | 20 | 60 | $3.1^{a}$ | $10.5^{e}$ | $1.4^{c}$ |
| $T_2$ | 20 | 90 | $2.8^{abc}$ | $13.0^{cd}$ | $1.6^{abc}$ |
| $T_3$ | 20 | 120 | $2.4^{bc}$ | $15.7^{a}$ | $1.9^{a}$ |
| $T_4$ | 35 | 60 | $2.8^{abc}$ | $12.2^{d}$ | $1.5^{bc}$ |
| $T_5$ | 35 | 90 | $2.7^{abc}$ | $13.7^{bcd}$ | $1.6^{abc}$ |
| $T_6$ | 35 | 120 | $2.2^{c}$ | $14.9^{ab}$ | $1.8^{a}$ |
| $T_7$ | 50 | 60 | $2.9^{ab}$ | $12.9^{cd}$ | $1.6^{abc}$ |
| $T_8$ | 50 | 90 | $2.4^{bc}$ | $14.3^{abc}$ | $1.75^{ab}$ |
| $T_9$ | 50 | 120 | $2.2^{c}$ | $14.6^{ab}$ | $1.66^{abc}$ |
| | Mean | | 2.6 | 13.5 | 1.6 |
| | Sig. | | ** | ** | ** |

Trts= treatments, PS= plant spacing, HA= harvesting date, LSR= leaf to stem ratio, DMY t/ha= total dry matter yield ton per hectare, CPY t/ha= total crude protein yield ton per hectare and Sig.= significance level.

### 4.6. Effects of Plant spacing and Harvesting Age on Chemical Composition and *In-vitro* Dry Matter Digestibility

The impact of plant spacing and harvesting age on the chemical composition and *in vitro* dry matter digestibility (IVDMD) of *Urochloa mutica* also evaluated. It was found that dry matter (DM) content significantly increased with narrower plant spacing and later harvesting ages, with the highest DM observed under these conditions. The ash content decreased as plant maturity increased and plant spacing widens, peaking at early harvesting age. Crude protein (CP) content was highest at narrow spacing (20 cm) during early harvesting age (60 days) and declined with advanced maturity.

Fiber content, including neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL), raised with maturity, with the highest levels of NDF and ADF noted at late harvesting ages. Concentration of ADL also increased with age, peaking in wider spaced plants at late maturity. Furthermore, IVDMD improved with wider plant spacing at early harvesting, was significantly higher in these conditions compared to narrow spacing and later harvesting ages. Interaction effects of both plants spacing and harvesting age on chemical content and digestibility were statistically significant ($p<0.05$).

Table 12. Percentage of nutritional composition and *in vitro* dry matter digestibility of *Urochloa mutica* as affected by plant spacing and harvesting age

| Trts | PS | HA | DM | Ash | CP | NDF | ADF | ADL | IVDMD |
|---|---|---|---|---|---|---|---|---|---|
| $T_1$ | 20 | 60 | $90.5^{d}$ | $11.4^{ab}$ | $13.7^{a}$ | $58.2^{c}$ | $33.6^{c}$ | $4.7^{bc}$ | $62.3^{bc}$ |
| $T_2$ | 20 | 90 | $92.6^{bc}$ | $10.6^{bcd}$ | $12.1^{b}$ | $61.7^{b}$ | $33.6^{c}$ | $5.8^{abc}$ | $59.0^{e}$ |
| $T_3$ | 20 | 120 | $94.4^{a}$ | $9.6^{e}$ | $10.8^{c}$ | $65.1^{a}$ | $35.7^{a}$ | $6.3^{ab}$ | $54.9^{f}$ |
| $T_4$ | 35 | 60 | $92.0^{c}$ | $11.8^{a}$ | $13.6^{a}$ | $58.6^{c}$ | $33.1^{c}$ | $4.9^{abc}$ | $63.1^{ab}$ |
| $T_5$ | 35 | 90 | $92.9^{bc}$ | $11.2^{abc}$ | $12.0^{b}$ | $62.7^{b}$ | $33.7^{bc}$ | $5.6^{abc}$ | $59.6^{de}$ |
| $T_6$ | 35 | 120 | $93.8^{ab}$ | $10.1^{de}$ | $10.2^{c}$ | $65.8^{a}$ | $35.8^{a}$ | $6.4^{ab}$ | $57.6^{e}$ |
| $T_7$ | 50 | 60 | $92.5^{c}$ | $12.0^{a}$ | $14.2^{a}$ | $59.2^{c}$ | $33.2^{c}$ | $4.5^{ab}$ | $64.6^{a}$ |
| $T_8$ | 50 | 90 | $93.0^{bc}$ | $10.7^{bcd}$ | $12.3^{b}$ | $62.8^{b}$ | $33.9^{bc}$ | $5.6^{abc}$ | $61.0^{cd}$ |
| $T_9$ | 50 | 120 | $93.1^{bc}$ | $10.3^{cde}$ | $11.9^{b}$ | $65.2^{a}$ | $34.5^{b}$ | $6.5^{a}$ | $58.1^{e}$ |
| | Mean | | 92.7 | 10.8 | 12.3 | 62.1 | 34.1 | 5.6 | 60.0 |
| | Sig. | | ** | ** | ** | ** | ** | * | ** |

Trts= treatment, PS= plant spacing, HA= harvesting age, DM= dry matter, CP= crude protein, NDF= neutral detergent fiber, ADF= acid detergent fiber, ADL= acid detergent lignin and IVDMD = *In vitro* dry matter digestibility

## 4.7.Chemical Composition of Experimental Feeds

The chemical composition of experimental feeds was presented in the table 16. The major ingredients considered in the ration were *Urochloa mutica* hay and concentrate. The concentrate feed was formulated from wheat bran 81.8%, noug seed cake 15.2% salt 1% and limestone 2% to balance the nutrient requirements, and mixed properly. The higher crude protein content observed in the concentrate might be due to concentrates are typically formulated with protein-rich ingredients (oilseed cakes).

Table 13. Chemical composition of provided feeds and refusals in percentage

| Variables | DM | Ash | CP | NDF | ADF | ADL |
|---|---|---|---|---|---|---|
| *U. mutica* | 93.1 | 14.3 | 12.3 | 65.9 | 36.1 | 5.9 |
| Concentrate | 90.0 | 5.7 | 21.2 | 37.7 | 8.9 | 2.6 |
| Refusal | | | | | | |
| $T_1$ | 95.0 | 5.8 | 1.98 | 74.1 | 48.2 | 9.1 |
| $T_2$ | 95.8 | 5.8 | 2.01 | 74.8 | 47.5 | 9.2 |
| $T_3$ | 94.0 | 5.6 | 1.96 | 72.3 | 48.2 | 10.2 |
| $T_4$ | 94.7 | 5.7 | 1.82 | 71.3 | 49.1 | 10.2. |

DM= dry matter, CP = crude protein, NDF = neutral detergent fiber, ADF = acid detergent fiber and ADL = acid detergent lignin

## 4.8. Feed Intake and Metabolizable Energy

The overall mean feed dry matter and nutrient intakes revealed significant variations among the treatments. Cows received treatments 1 and 2 exhibited the highest dry matter intake, while those supplemented with the lowest level of concentrate ($T_4$) had the lowest intake at 6.79 kg DM/day. The lowest dry matter intake in $T_4$ might be due to the diet was high in indigestible fiber and lignin, low in protein, and low in energy density, which reduces palatability, rumen turnover, and microbial efficiency. Crude protein intake followed a similar trend, with significantly ($p<0.05$) higher levels recorded for cows on higher concentrate supplements ($T_1$), while those on $T_2$, $T_3$, and $T_4$ had comparatively lower intakes.

Additionally, intakes of neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL) significantly differed ($p<0.05$) among the treatment groups, particularly with cows on $T_4$ showed higher levels of these components compared to those on $T_2$, $T_3$, and $T_1$. Similarly, effects of dietary treatments on the metabolizable energy (ME) intake of cross-bred dairy cows were indicated significant differences among treatment groups. Specifically, the cows in treatment one ($T_1$) exhibited comparable and significantly higher ME levels in comparison to those in treatments two and three. Furthermore, it was noted that the level of ME increased alongside the concentrate level included in their rations.

Table 14. Nutrient intake of cross-bred dairy cows as influenced by dietary treatments

| Treatment | DMI | CPI | NDFI | ADFI | ADLI | ME(MJ/kg) |
|---|---|---|---|---|---|---|
| $T_1$ | 12.8$^{a}$ | 1.85$^{a}$ | 7.0$^{a}$ | 2.74$^{a}$ | 1.34$^{a}$ | 9.6$^{a}$ |
| $T_2$ | 12.7$^{ab}$ | 1.67$^{ab}$ | 6.1$^{b}$ | 2.4$^{ab}$ | 1.26$^{b}$ | 8.1$^{ab}$ |
| $T_3$ | 9.3$^{c}$ | 1.11$^{c}$ | 5.2$^{c}$ | 2.06$^{b}$ | 1.19$^{c}$ | 7.9$^{ab}$ |
| $T_4$ | 7.3$^{d}$ | 0.76$^{d}$ | 4.2$^{d}$ | 1.65$^{c}$ | 1.11$^{d}$ | 6.1$^{b}$ |
| Mean | 9.7 | 1.3 | 5.6 | 2.2 | 1.2 | 7.9 |
| Sig. | *** | ** | *** | ** | *** | * |

DMI=dry matter intake, CPI= crude protein intake, NDFI= neutral detergent fiber intake, ADFI= acid detergent fiber intake and ADLI= acid detergent lignin.

### 4.9.Milk Yield and Composition

The data revealed statistically significant differences ($P<0.05$) observed in overall mean milk yields across treatment groups, notably demonstrating that cows on treatments $T_1$ and $T_2$ produced higher milk yields in comparison to those on treatment $T_4$. In terms of milk composition, the dietary treatments significantly impacted the fat and lactose contents. The highest fat content recorded was 4.1% in treatment group $T_4$, whereas treatment $T_1$ exhibited the lowest fat content. If milk price is determined by fat content like others countries, $T_4$ is the most profitable option despite lower yield, because it produces milk with the highest fat percentage. The investigation encountered a notable trend where milk fat content was inversely related to the concentrate levels: it increased when less concentrate was supplemented.

In lactose content, $T_1$ and $T_2$ showed significantly ($p<0.05$) higher levels when compared to $T_3$ and $T_4$. The lactose levels increased with higher concentrate supplementation initially, followed by a decline as supplementation was reduced. Similar trends were observed with protein content. Conversely, the ash content did not show significant changes across the various feed treatments groups. Moreover, the study highlights significant differences in total solids (TS) and solid-not-fat (SNF) among the treatment groups ($p<0.05$), with $T_1$ displayed the highest TS at 12.50% and SNF at 9.67%. In contrast, treatment $T_4$ yielded the lowest values of 11.56% for TS and 8.20% for SNF.

Table 15. Milk yield and composition of cross-bred dairy cows kept on *Urochloa mutica* basal feed with graded level of concentrate

| Trts | DMY(L) | Fat (%) | Lactose (%) | Protein (%) | Ash (%) | TS (%) | SNF (%) |
|---|---|---|---|---|---|---|---|
| 1 | $11.6^{a}$ | $3.5^{c}$ | $5.6^{a}$ | $4.6^{a}$ | $0.68^{a}$ | $12.5^{a}$ | $9.7^{a}$ |
| 2 | $10.9^{ab}$ | $3.6^{bc}$ | $5.4^{a}$ | $4.5^{a}$ | $0.69^{a}$ | $12.1^{b}$ | $8.8^{b}$ |
| 3 | $10.2^{bc}$ | $3.8^{b}$ | $5.1^{b}$ | $4.3^{b}$ | $0.69^{a}$ | $11.9^{b}$ | $8.5^{b}$ |
| 4 | $9.7^{c}$ | $4.1^{a}$ | $4.9^{b}$ | $4.3^{b}$ | $0.69^{a}$ | $11.6^{c}$ | $8.2^{b}$ |
| Mean | 10.6 | 3.8 | 5.2 | 4.3 | 0.68 | 12.0 | 8.8 |
| Sig. | ** | ** | * | ** | NS | ** | * |

Trts= treatments, DMY= daily milk yield, TS= total solids and SNF= solids-not- fat

## 4.10. Cost Benefit Analysis

The experiment utilized several variable costs, including *U. mutica* hay priced at 190 birr per bale, mixed concentrate at 2300 birr for 100 kg, and labor costs of 125 birr per man per day. Each bale of *U. mutica* weighed 14 kg, and a total of four men were employed throughout the experimental period. Income from the experiment was derived from milk and dung cake sales, with milk priced at 65 birr per kilogram and dung cake at 2 birr per piece. All relevant costs and income data were sourced from Holetta town.

Accordingly, to assess the economic benefits, a partial budget analysis was conducted, which highlighted the most rewarding treatment. The analysis indicated that the highest net benefit amounted to 541.95 birr from treatment $T_2$, which also had the highest marginal rate of return (MRR) of 315.45%. The results clearly indicated that the treatment yielding the most significant economic advantage for small-scale farmers was $T_2$, which combines *U. mutica* DZF-483 adliptum with 0.4 kg of mixed concentrate for every liter of milk produced.

Table 16. Calculated marginal rate of return in cows fed on *Urochloa* mutica and graded level of concentrate

| Variables | $T_1$ | $T_2$ | $T_3$ | $T_4$ |
|---|---|---|---|---|
| MY (L) | 11.6 | 10.9 | 10.2 | 9.7 |
| Dung cake (pcs) | 10 | 9 | 7 | 6 |
| Revenue | 754.1 | 713.7 | 662.4 | 631.9 |
| TVC | 215.2 | 171.8 | 168.5 | 163.4 |
| Net benefit | 538.8 | 541.9 | 493.9 | 468.5 |
| MRR% | 250.4 | 315.4 | 293.2 | 286.6 |

MYL (L)= Milk yield in litter, TVC= Total variable cost, MRR= Marginal rate of return

# 5. DISCUSSION

In this section, results from the three experiments were discussed in the orders presented in the preceding section. Therefore, results of forage agronomic performance, yields, and nutritional composition of *Urochloa mutica* were deliberated below. As well as its animal response (feed intake, milk yield, milk composition, and digestibility) were discussed.

## 5.1.Effects of Fertilizer Types on Morphological Characteristics and Yields

The significantly higher ground cover observed in $T_2$ and $T_4$ (9.8 and 8.8, respectively) compared to the control group (6.7) indicated that, *U. mutica* needed adequate nutrient availability to express its stoloniferous growth habit. These results were consistent with Mesfin *et al.* (2021), who noted the ability of *Urochloa mutica* to form dense creeping mats under favorable conditions. The increased in tiller numbers and leaf length in this study likely facilitated the rapid spread of culms, supported the assertion by Beyadgilign *et al.* (2024) who stated that, the grass was highly effective for soil coverage and sustainable fodder production.

The average plant height of *Urochloa mutica* as affected by fertilizer types was lower than the value of Fantahun *et al*. (2024); Ketema *et al.* (2024), who reported 116.2 at Bishoftu Agricultural Research Center and 160 at Bore Agricultural Research Center, for *Urochloa mutica* respectively. The lower value recorded in the current study was due to the experiment aimed at harvesting approximately around one meter in length. However, the nearly comparable plant height of $T_4$ (75% NPS and 25% vermicompost) with $T_2$ (100% NPS) might be attributed to the optimal combination of fertilizers and the synergistic effects of nutrients that were equivalent to the NPS fertilizer, which support essential plant functions and promote enhanced growth in *Urochloa mutica* height.

The combined application of NPS and vermicompost fertilizer increased the number of tillers in *Urochloa mutica* compared to using no fertilizer. Combining these fertilizers, particularly a blend of 75% NPS and 25% vermicompost, enhanced nutrient availability, leaded to a greater number of tillers. This showed that the combined application of 75% NPS + 25% vermicompost formed better bunches of *Urochloa mutica* over the control/unfertilized treatment and the sole use of vermicompost. The optimum combination of NPS and vermicompost fertilizer might enhanced the development of new shoots and encouraged the development of new tillers. The result obtained in this study was partially in agreement with the finding of Zakirul *et al.* (2020), who reported that the highest tiller numbers of *Urochloa ruziziensis* were found in treatment groups treated with cow dung over the control group (treatment group without fertilizer) in Thailand.

Combining vermicompost with NPS fertilizer significantly enhanced *Urochloa mutica* leaf length and number per plant, with a combination of 75% NPS and 25% vermicompost showed comparable results to 100% NPS. The highest value of number of leaves per plant (1369.9) was recorded with 75% NPS and 25% vermicompost due to the availability of a sufficient amount of nutrients for plant growth through vermicompost and NPS fertilizer. Tesfaye, (2022) reported an increased in the number of leaves per plant of maize in response to the combined application of vermicompost and NPS fertilizer. Wilgince *et al*. (2007) also reported an increase in the number of leaves per plant in the second harvest of *Urochloa brizantha* treated with farmyard manure in Mexico.

Additionally, the higher and comparable values of leaf length, 31.6 and 30.2 cm, were observed in the sole NPS and 75% NPS and 25% vermicompost applied groups, respectively. This could be attributed to increased vegetative growth in *Urochloa mutica*, driven by greater nutrient availability following fertilization. The overall mean obtained in this study, 25.9 cm, was slightly higher than the finding of Beyadglign *et al*. (2022), who reported 22 cm for *Urochloa mutica* grown under rainfed conditions at the Andassa Livestock Research Center, and Zakiru *et al*. (2020), who reported the highest leaf length (23.7 cm) in *Urochloa ruziziensis* in plots fertilized with cow dung in Thailand, but it was lower than the report of Beyadgilign *et al*. (2024), who reported 28.9 cm for *Urochloa mutica* at 120 days of harvesting. The differences might be due to differences in agroecology and management conditions.

The below-ground forage parameters, like root parameters, are becoming increasingly important, equally like the biomass, since they affect the quality, quantity, and sustainability of the established forage in the production area. Forage plants with better roots keep the soil in place, improve soil fertility, and reduce water leaching and soil erosion (Beyadgilign *et al.*, 2019). The root parameters also serve for better soil nutrient absorption and critically determine the overall grass performance by increasing the grass tillering performance (Veras *et al.*, 2020).

The combined application of vermicompost and NPS fertilizer significantly increased the number of roots per plant of *Urochloa mutica*, compared to using either fertilizer alone. The integrated approach combined the benefits of vermicompost's long-term soil-building properties with the rapid nutrient release of NPS fertilizer (Wakgari, 2022). The average NRPP of 98.5 obtained in this experiment was comparable with the value of 105.5 reported by Beyadglign *et al.* (2022) for *Brachiaria* mutica planted on red soil and fertilized with 100 kg/ha NPS and 50 kg/ha urea at the Andassa Livestock Research Center, Ethiopia.

As root length increased, water and mineral absorption significantly improved, enhanced the establishment and sustainability of *Urochloa* grasses in the production area. This is because greater root length reduced the distance nutrients must travel to reach the roots (Wakgari, 2022). Forage producers should simultaneously consider soil type, fertilizer application, and the choice of *Urochloa* grass cultivars during forage establishment. The overall mean (15.9 cm) RLPP of the present study was comparable with the report of Mamilla *et al.* (2020), who reported 15.59 cm for *Urochloa mutica* at Bahir Dar town and the Shum Abo elementary school compound.

Grasses with higher LSR are favored in animal nutrition since it is an important factor affecting diet selection, quality, and intake of forage (Garay *et al.*, 2017). Higher leaf biomass fractions had lower NDF concentrations than stems (Kevin *et al*., 2021). Leafy biomass is usually retained in the rumen for a shorter period than stems because of faster rates of NDF digestion and higher rates of passage (Delagarde *et al*., 2000). In the current finding, the overall mean of the leaf-to-stem ratio of *Urochloa mutica* (2.5) was higher than the report of Beyadglign *et al*. (2022), who reported 1.63 at the Andassa Livestock Research Center, and lower than the report of Beyadgilign *et al.* (2024), who reported 3.08 for *Urochloa mulatto* II at 90 days of harvesting and fertilized with 200 kg/ha NPS at the time of establishment and 50 kg/ha urea after 30 days of planting at the Wolaita Sodo state dairy farm in southern Ethiopia. The differences might be attributed to variation in management, environment, and cultivar.

In the circumstance of dry matter yield, the highest value in total biomass accumulation over the control might be due to the good response of *Urochloa* grass to the sole NPS and synergistic effects of vermicompost and NPS fertilizers, which were well-recognized for the vegetative growth of plants. In agreement with this finding, Tesfaye (2022) reported that the total dry matter yield of maize was higher from treatment combinations of vermicompost and NPS fertilizers than from control groups at the Toke Kutaye District, Ethiopia. Ogedegbe and Ewansiha (2016) also reported the highest dry matter yield of Rhodes grass (*Chloris gayana*) treated with poultry manure over urea and NPK fertilizer in Nigeria. So, the overall mean of dry matter yield, 14.6 t/ha, obtained in the current finding was lower than the value of 20.37 t/ha for *Urochloa mutica* at the Andassa Livestock Research Center (Beyadglign *et al*., 2022). Nonetheless, the result reported was slightly higher than the report of Fantahun *et al. (2024),* who reported 13.57 t/ha at Bishoftu Agricultural Research Center.

## 5.2.Effects of Fertilizer on Chemical Composition

All fertilized treatments ($T_2$–$T_6$) significantly increased crude protein (CP) compared to the control. There was no statistically significant difference between 100% chemical ($T_2$) and 100% organic ($T_3$) for CP, suggested that, vermicompost was a viable protein booster. On the other hand, as fertilizer improved, neutral detergent fiber (NDF) and acid detergent lignin (ADL) decreased. High lignin (as seen in $T_1$) is a known barrier to digestion, which explains why $T_1$ had the lowest digestibility. There was a clear inverse relationship between fiber/lignin and digestibility. $T_2$ (100% NPS + Urea) was most digestible and followed closely by $T_4$ (75% NPS + 25% Vermicompost).

In agreement with this study, the CP result obtained in this study was slightly similar to the findings of Zakiru *et al.* (2020), who reported significantly higher CP content in *Urochloa ruziziensis* treated with cow dung and urea fertilizer based on nitrogen content in Thailand. The NDF composition of the feed obtained in this study (67.45%) was in close agreement with Beyadglign *et al.* (2022), who reported the NDF composition of 70.1% in *Urochloa* grasses fertilized with blended NPS (100 kg/ha) and urea (50 kg/ha) at Ambo Mesk, Mecha District, and Andassa Livestock Research Center. Additionally, the IVDMD of the current study is slightly similar to the report of Fantahun *et al*. (2024), who reported an IVDMD range of 50-59 for different *Urochloa* cultivars fertilized with urea at the Debre Zeit Agricultural Research Center. Beyadglign *et al.* (2022) also reported slightly comparable results, with an IVDMD of 60.68% for *Urochloa* grasses.

## 5.3.Economic Feasibility of *Urochloa mutica* as Influenced by Fertilizer

Analysis of the economic feasibility indicated that $T_2$ (100% NPS + 100% urea) achieved the highest net benefit (128,018.7) and the highest adjusted hay yield (16,272.7 kg/ha). Highest efficiency was observed in $T_4$ (75% NPS + 25% vermicompost), which yielded the highest marginal rate of return (175.2%), indicated the best return for every additional unit of investment among the non-dominated options. $T_5$ and $T_6$ were classified as "dominated." This means their costs were higher than other treatments while provided lower net benefits; essentially, they were not economically rational choices compared to $T_4$ or $T_2$.

In general, in NPS fertilizer, rapid nutrient release, higher leaf length, tiller numbers, and biomass and; in vermicompost**,** improved soil fertility, root development, and sustainable nutrient supply observed. Combined NPS and Vermicompost (75:25) balanced nutrient availability, optimal tiller and leaf production, better root systems, and improved forage quality (higher LSR, sustainable yield). The integration of NPS and vermicompost provided the best balance between yield and forage quality, enhancing both above-ground (leaves, tillers, biomass) and below-ground (roots) traits, which are crucial for sustainable fodder production and soil health. In other words, NPS fertilizer is like a sprint**,** giving plants a quick boost, while vermicompost is the marathon runner**,** ensuring endurance and sustainability. Together, they create a balanced system that maximizes both yield and quality, exactly what's needed for sustainable fodder production in Ethiopia.

### 5.4.Effects of Plant Spacing and Harvesting Age on Morphological Characteristics and Yields

Ground cover of *Urochloa mutica* was significantly affected by both plants spacing and harvesting age. At the narrow spacing (20 cm), the ground cover reached its peak (93%) at 120 days, suggested the grass was highly effective for soil stabilization in the region. The overall mean ground cover of *Urochloa mutica* (8.8%) obtained in this study was in parallel with the value 8.1% reported by Fantahun *et al.* (2024) on *Urochloa grasses* at Bishoftu Agricultural Research Center.

Plant height increased progressively as the space between plant and harvesting age increased (Natsenet, 2024). An increment in plant height (PH) at later harvest stages could be due to massive root development and efficient nutrient uptake, allowing the plant to continue to increase in height of the grass (Babale *et al.*, 2020). The expected increment in plant height at advanced maturity was in agreement with the findings of Babale *et al.* (2020), who reported for *Urochloa ruziziensis* grass treated with NPK fertilizer in Nigeria. The mean plant height (96.16 cm) from the current results was higher than that reported by Endalkachew, (2021) (63.53 cm) at Mecha District and lower than the report of Mamilla *et al. (*2020) (180 cm) on *Brachiaria mutica* at different plant spacing and harvesting ages at Bahir Dar, Ethiopia. The difference might be attributed to differences in management, soil type, climatic conditions and the time of harvest.

The numbers of tillers per plant in narrow, intermediate, and wider plant spacing were numerically different but not significantly different at late harvesting age. This might be due to late harvesting age; the plant will achieve higher maturity, and this gives an advantage to massive tiller shoot development. This finding was supported by Wondimagegn *et al*. (2021), who reported that as the plants approached maturity, numerous tillers appeared, growing out from the leaf axils of the main stems. Tiruset *et al*. (2022) reported the higher NTPP at late harvesting age (120 days) in the North *Mecha* district at *the Ambomesk* Peasant Association's Northwestern Ethiopia. The mean number of tillers per plant recorded in this study, 141.93, was slightly comparable with the result of Edalkachaw (2021), who reported 132.83 for *Urochloa hybrid mulatto* II treated with 100 kg/ha of urea at Mecha District, Ethiopia.

Consequently, with the increase in the stage of maturity, the greater the number of leaves, which are important for the photosynthetic and transpiration surface, that were produced from the newly emerging tillers (Getnet *et al.* 2017). The current result was supported by Getnet *et al.* (2017), Bimirew *et al.* (2017) ; Wangchuk *et al. (2015),* who stated that, the number of leaves per plant was significantly affected by the harvesting date of grasses. The mean number of leaves reported in the present study, 990.13, was slightly comparable with the report of Endalkachew (2021), who reported 1037.30 as the mean number of leaves per plant for *Urochloa hybrid mulato* II treated with 100 kg/ha of urea through different plant spacing and harvesting ages at Mecha District, Ethiopia.

Leaf length was increased progressively with enhanced age of harvesting, and this was supported by the finding of Natsenet (2024) on Desho grass in the Basona Werena district, North Shewa Zone of the Amhara Region, and Tiruset *et al.* (2022) at Ambomesk Peasant Association. This was because leaf length in grasses is greatly influenced by the developmental stage of the plant: reproductive or vegetative. The mean leaf length recorded in the current study, 26.36 cm, was slightly lower than the finding of Diribi and Aman (2022), who reported 31.58 for *Urochloa* grass treated with different levels of blended NPS fertilizer through different harvesting dates at Wondo Genet, Ethiopia, and higher than the report of Wubetie *et al*. (2018), who reported 19.38 cm as the highest leaf length of *Urochloa brizantha* grasses treated with DAP and urea through different harvesting ages and plant spacing in the mid-altitude of Northwestern Ethiopia. This difference might be due to different managements, plant spacing, weather conditions, soil type, and cultivar.

The number of roots increased linearly with the maturity of the plant. Roots spring out from nodes, and the total number of nodes per plant determines the total number of roots even if the varietal differences in the average number of roots are observed (Nguku, 2015). The mean number of roots per plant, 114.23, obtained in this experiment was comparable with the report of Nagasu *et al.* (2020), who reported 142.3 for *Urochloa mutica* fertilized with DAP and urea through different plant spacing and harvesting ages at Bahir Dar, Ethiopia.

Also, an increase in root length increases absorbing surface; thus, they may be important for water and mineral absorption. The explanation was that the uptake of a different nutrient in competing plants was proportional to the root length, as the greater the root length, the shorter the distance the nutrient has to travel to the root. The mean root length obtained in this study, 18.28, was somewhat comparable with the report of Nagasu *et al.* (2020), who reported 15.59 cm for *Urochloa mutica* at Bahir Dar. But the current result was disagreed with the report of Endalkachew (2021), who reported 43.70 cm for *Urochloa hybrid Mulato II* fertilized with 100 kg/ha urea through different plant spacing and harvesting ages at Mecha District, Ethiopia. The difference might be due to the variation in weather condition, management, cultivar, and soil type.

LSR sharply declined as the harvesting ages increased. This might be the accumulation of more cell wall components in plant tissues as a result of stem development with advancing maturity (Beyadgilign *et al.*, 2024). The mean of LSR reported in this study, 2.5, was slightly higher than the report of Diribi and Aman (2022), who reported 2.29 LSR for *Urochloa grass* fertilized with graded levels of NPS fertilizer through different harvesting ages at Wondo Genet, Ethiopia. This difference might be due to environmental conditions, agronomic practices, fertility, and moisture content of the soil.

On the other hand, as grass matures, herbage yield is increased due to the rapid increase in the tissues of the plant, development of additional tillers and leaf formation, leaf elongation, and stem development with increasing plant age (Getnet *et al.* (2017). The highest DMY recorded in this study from narrow plant spacing at late harvesting age shows that the number of plant population means a greater number of plant populations and numbers of tillers, stems, and leaves per unit area at narrow plant spacing. Also, the competition between individual plants for solar energy led to maximized plant height and leaf length that increased biomass yield at narrow spacing. Additionally, for more biomass yield, narrow spacing could mean more established plants, which make use of the available resources without giving a chance for the weed. The overall mean of dry matter yield, 13.5 t/ha, reported in the current finding was relatively lower than the finding of Nagasu *et al*. (2020), who reported 14.59 t/ha dry matter yield of *Brachiaria Hybrid Mulato* II grass fertilized with different levels of NPS fertilizer through different plant spacing at the Lowlands of Northwest Ethiopia**,** and higher than the report of Wondimagegn *et al*. (2021), who reported 9.18 t/ha for hybrid *Urochloa* cv. *mulato II* grass fertilized with different levels of NPS fertilizer through different plant spacing at Chagni Ranch, Awi Zone. This difference might be due to management, environmental conditions, cultivar, soil moisture, and fertility of the grass.

Crude protein yield was increased when spacing between plants was reduced at advanced maturity, and this result is supported by Yerosan *et al.* (2023). This might be due to the fact that CPY is the product of total dry matter yield and CP concentration in the plant. The mean of crude protein yield obtained in this study 1.6 t/ha was comparable with the report of Endalkachew, (2021), who reported 1.55 t/ha CPY for *Urochloa hybrid mulatto* II fertilized with 100 kg/ha urea through different plant spacing and harvesting ages at Kudmi site, North Mecha District, Ethiopia.

## 5.5. Effect of Plant Spacing and Harvesting Age on Chemical Composition

As the grass stays in the field longer, the crude protein and ash content generally decreased. For instance, in $T_1$ through $T_3$, CP drops from 13.7% to 10.8%. Structural components, NDF (neutral detergent fiber), ADF (acid detergent fiber), and ADL (lignin) increased. Because fiber and lignin increase with age, the IVDMD (in vitro dry matter digestibility) significantly dropped, meaning the forage becomes harder for livestock to digest as it matures (Genet *et al.*, 2017). The highest digestibility observed in $T_7$ (50 cm spacing, 60 days) actually recorded the highest IVDMD (64.6%), suggested that wider spacing might allow for better individual plant development, though it was related to younger harvest ages (like $T_4$ or $T_1$) for maximum protein. The highest protein in $T_7$ (14.2%) and $T_1$ (13.7%) represented the peak CP levels, both occurred at the lower end of the maturity spectrum for their respective spacing groups.

In contrast, the mean dry matter content reported was 92.75, which was comparable with the report of Aysheshim *et al.* (2022), who reported 92.6 for *Urochloa* grass, which was fertilized by 100 kg/ha of urea and 50 kg/ha of DAP at Mecha District, Northwestern Ethiopia, at Kudmi kebele. The mean CP content obtained (12.3%) was slightly lower than the report of Endalkachew (2021), who reported 14.71% mean CP for *Urochloa hybrid mulatto* II, and higher than the report of Aysheshim *et al.* (2022), who reported 11.6% CP content of *Urochloa* grass fertilized by 100 kg/ha of urea and 50 kg/ha of DAP at Mecha District, Northwestern Ethiopia. The mean of ADF content observed in this study (34.12) was slightly comparable with the finding of Diribi and Aman (2022), who reported 31.77% ADF content of *Urochloa* grass at Wondo Genet, Ethiopia. The average result of IVDMD obtained in the current study was comparable with the report of Beyadgilign *et al*. (2023), who reported 60.68 for different *Urochloa* grasses at Andassa Livestock Research Center and Ambo Mesk, Mecha district.

In general, closer plant spacing and later harvesting age enhanced biomass and protein yield, while earlier harvests favored forage quality (higher LSR and digestibility). Plant spacing and harvesting age strongly determine the trade-off between forage yield and quality. Early harvests and wider spacing favor quality, while late harvests and narrow spacing favor quantity.

On the other hands, based on the grass's parameters evaluated in experiment I and II, *Urochloa mutica* positively contributed in natural resource conservation, drought resilience and carbon sequestration. Dense ground cover (up to 93% at narrow spacing) and strong root proliferation (114+ roots per plant) might reduce soil erosion, stabilize slopes, and suppress weeds. Additionally, vermicompost integration improved soil organic matter and microbial activity and enhanced long-term fertility. Water retention extensive root length (up to 18 cm) improved infiltration and reduced leaching, conserved water resources clearly indicated the contribution of *Urochloa mutica* in natural resource conservation.

Contribution of *Urochloa mutica* to drought resilience through longer roots increased water uptake efficiency which allowed the survival under limited rainfall. Leaf to stem ratio declined with age, younger harvests provided leafy biomass that was more water-efficient in growth and recovery. Wider spacing reduced competition for soil moisture, making plants more resilient in dry conditions. Combined NPS and vermicompost enhanced nutrient availability, supported plant vigor even under stress.

High dry matter yield (up to 14.6 t/ha) contributed to carbon storage in plant tissues. Dense root systems added organic carbon to soils, improved soil structure and long-term carbon sequestration. Integrated fertilization (NPS + vermicompost) and optimal spacing increased biomass turnover and soil organic carbon accumulation. Lower lignin content in younger harvests means faster cycling of carbon through livestock systems, while mature stands contributed more stable carbon to soils. In short, the agronomic traits studied don't just improved forage yield and quality**,** they also translated into ecosystem services**,** soil protection, water conservation, resilience to climate stress, and carbon storage.

### 5.6.Feed Chemical Composition in Feeding Experiment

Concentrate was the most nutrient-dense component, boasted the highest crude protein (CP) at 21.2% and the lowest fiber content (NDF 37.7%, ADF 8.9%). *U. mutica* **c**ontains 12.3% CP and significantly higher fiber levels (NDF 65.9%) compared to the concentrate. The refusal, $T_1$-$T_4$ show very low protein levels, ranging from 1.82% to 2.01%. This indicated the animals successfully selected the protein-rich components of the diet. The refusals were heavily concentrated with indigestible or less palatable fibers. NDF levels in refusals (71.3%–74.8%) were higher than in the original *U. mutica*, and ADL (lignin) levels nearly doubled in some cases (up to 10.2%), showed that animals rejected the woodier, stemmier parts of the forage. Also, the refused material is consistently dried (94.0%–95.8%) than the initial feed offerings.

In contrast, the dry matter (DM) content of *U. mutica* hay in the current study agreed with the mean dry matter content of *Brachiaria mutica*, 93.89%, reported by Beyadglign *et al. (2019)* at the Andassa Livestock research center. The dry matter content of formulated concentrate is slightly comparable with the result (91.09%) reported by Geleta and Damisu (2020). The crude protein content of *U. mutica* grass hay reported in this study was comparable with the result of 12.7% reported by Fantahun *et al. (2024)*. The crude protein content of formulated concentrate feed was 21.20% and comparable with the report of Baysa *et al.* (2023), who reported 21.5 for mixed concentrate in the Tigray region.

The NDF content of formulated concentrate feed and *U. mutica* grass hay was 37.7% and 65.89%, respectively. In addition, the result of neutral detergent fiber content of formulated concentrate feed in this study was slightly comparable with the report of Dereje and Temesgen (2016), who reported 36.45%. The neutral detergent fiber (NDF) content of *U. mutica* grass hay was in line with the value (64.9%) reported by Solomon *et al.* (2022) on *the Urochloa* hybrid cultivar in Tanzania.

The ADF and ADL of the formulated concentrate obtained in the experiment were 8.92 and 2.57, respectively. These results were comparable with the findings of Gelane and Mitiku (2018), who reported 9.63 and 2.67 for ADF and ADL, respectively. Similarly, the ADF and ADL of *U. mutica* reported in this experiment were 36.07 and 5.90, respectively. The result reported was slightly comparable with the report of Solomon *et al*. (2022), who reported 36.5 and 8.0 for ADF and ADL, respectively.

## 5.7.Feed and Nutrient Intake

There was a clear, progressive decrease in almost every nutritional parameter from treatment 1 through treatment 4. Treatment 1 showed the highest voluntary intake across all categories. Dry matter intake dropped from 12.8 kg to 7.3 kg, the crude protein intake dropped significantly by nearly 59%. This suggested that the restriction in intake due to reduced concentrate level and the quality of the feed in treatment 4 severely limits protein availability. The reduction in fiber intake mirrors the dry matter intake. This indicates that the animals in the lower concentrate receiving groups were consumed less total bulk, rather than increasing intake and just changing the fiber-to-protein ratio. The lowest neutral detergent fiber intake recorded in cows in $T_4$ might be attributed to the lowest total dry matter intake and lower concentrate proportion in the ration, and this is supported by Quang *et al*. (2015), who elaborated that, a lower concentrate proportion in cross-bred dairy cow feed results in decreased net digestible energy (NDE) intake and total dry matter intake and a subsequent decline in milk production and body weight gain. The metabolizable energy (ME) drops from 9.6 MJ/kg in treatment 1 to 6.1 MJ/kg in treatment 4. An ME of 6.1 is quite low for a dairy cow. Increasing the energy density of the diet boosts milk yield and dry matter intake, while treatments like higher forage ratios can decrease digestibility and intake.

In contrast, the mean dry matter intake of 9.76 kg/day of the current study was comparable with the report of Getu *et al.* (2015), who reported 9.74 kg/day of the average dry matter intake of high-grade dairy cows at the Holetta Agricultural Research Center. The low dry matter intake recorded in cows supplemented with $T_4$ might be attributed to the higher neutral detergent fiber content of *U. mutica* hay due to the lower proportion of concentrate that is in turn negatively associated with intake (Arelovich *et al.*, 2008). The overall mean (7.9 MJ/kg) obtained in the study was slightly higher than the result of Beyadglign *et al.* (2023), who reported 7.72 MJ/kg for different *Urochloa* grasses at the Andassa Livestock Research Center and the Ambo Mesk mecha District. The differences might be due to agro-ecologies and management.

## 5.8.Milk Yield and Composition

Significant decrease in milk production from treatment 1 (11.6 L) to treatment 4 (9.7 L) was observed. This suggests that the dietary energy was highest in treatment 1 due to the high level of concentrate in the ration, favoring volume. Interestingly, while yield decreased, the fat percentage increased significantly, rising from 3.5% ($T_1$) to 4.1% ($T_4$). This indicated that, a higher fiber-to-concentrate ratio in treatment 4. Both protein and lactose components showed a downward trend as yield decreased. Treatment 1 had the highest protein (4.6%) and lactose (5.6%), both of which are key indicators of good energy status in dairy cows. Total Solids and solids-not-fat followed the trend of the yield and protein/lactose levels.

In contrast, the result daily milk yield obtained in $T_1$ and $T_2$ was comparable, and this might be encouraged to decide the proper level of concentrate that should be provided with *Urochloa mutica* for optimum milk yield. The average daily milk yield (10.6) obtained in the current finding was slightly comparable with the study of Solomon *et al. (2022),* who reported the average milk yield (10.2) for cross-bred dairy cows fed *Urochloa* hybrid *mulatto* II with concentrate supplementation in the Njombe district, Tanzania. Also, the average fat content (3.77) of milk reported in the current study was slightly comparable with the study of Mesfin *et al.* (2023), who reported 3.68 for local and Friesian cross-bred recorded in the Sodo Zuria district, Wolaita Zone, of southern Ethiopia.

Accordingly, the average CP content in the current study was slightly comparable with the report of Aemiro *et al.* (2010), who reported 4.89 for cross-bred dairy cows fed with different levels of vetch hay and concentrate on a basal diet of fresh-cut Napier grass at the same center. Consequently, the average total solid observed in this study was slightly in parallel with the findings of Mirzadeh *et al.* (2010) and Fikadu (2024), as they reported 12.33 in Namibia, 12.57 in the Lordan region of Iran, and 12.58 in the Dire dawa area, respectively.

The average solid not fat recorded in the current study was slightly comparable with the finding of Tegegn *et al*. (2024), who reported 9.29 for cross-bred dairy cows fed a variety of feedstuffs such as green forages, grass hay, crop residues, concentrates (commercial mixes), and agro-industrial by-products at different locations across Addis Ababa City Administration, Oromia, Amhara, South Ethiopia, Central Ethiopia, Sidama, and Southwest People's Regional States of Ethiopia. In addition, the average lactose content of milk obtained in this experiment was slightly comparable with the report of Tolesa *et al*. (2015), who reported 5.07 in the urban and peri-urban areas of Dangila town, Amhara region, Ethiopia.

## 5.9.Economic value

The marginal rate of return represents the additional net gain for every additional unit of cost incurred. $T_2$ provided the highest net benefit (541.9) with a relatively low cost despite having a lower milk yield (10.6 L) than $T_1$ (11.9 L). $T_1$ was "dominated" or uneconomical because it has a higher cost (215.2) but a lower net benefit (538.8) than $T_2$, resulted in a negative marginal return. The marginal rate of return (MRR) is the ratio of the change in net benefit to the change in total variable cost between two treatments, and $T_2$ was the most economically efficient option, as it yielded the highest net benefit (541.9) before returns begin to diminish in $T_1$.

# 6. CONCLUSSIONS AND RECOMENDATIONS

Integrated fertilization balanced immediate nutrient demand with soil fertility conservation, ensured both productivity and resilience. Also. close spacing enhanced resource use efficiency and ecological sustainability by reduced competition from weeds and improved water retention. Harvest age created a trade-off between forage quality and quantity, required strategic decisions based on livestock needs (protein vs. bulk feed). Feeding strategies must align with market demand, protein-rich milk for nutritional value or fat-rich milk for processing industries. Likewise, above-ground traits (leaves, tillers, biomass) directly improve forage supply while below-ground traits (roots, soil fertility) strengthen drought resilience and long-term sustainability.

In general, the study demonstrated that *Urochloa mutica* productivity and nutritional quality can be optimized through integrated agronomic practices. Chemical fertilizer ensured maximum yield, while vermicompost sustained soil fertility. Narrow spacing improved ecological efficiency, and harvest timing balanced forage quality versus quantity. Feeding strategies fined-tune milk composition and profitability. Together, these practices form a sustainable intensification model that supports Ethiopia's *Yelemat Tirufat* program by boosting livestock productivity while safeguarding soil and ecosystem health. Therefore, based on the conclusion above the recommendations will be as follows:

1. In fertilizer Strategy, $T_4$ (75% NPS + 25% vermicompost) was most cost-efficient, with high marginal return and nearly as effective as $T_2$. Therefore, $T_4$ was recommended for sustainable systems, but apply $T_2$ when short-term yield and digestibility are the priority.
2. In planting spacing, narrow spacing (20 cm) was recommended.
3. In harvest age, combine narrow spacing with strategic harvest timing depending on whether protein quality or bulk yield is prioritized.
4. In Feeding strategies, $T_2$ feeding strategy is optimal for profitability, while concentrate adjustments can be made depending on whether milk protein or fat is more valued.

**5.** Integrated fertilization ($T_4$), narrow spacing (20 cm) with strategic harvest timing and balanced feeding ($T_2$) combination guaranteed sustainable soil health, strong forage growth, cost efficiency, and optimal milk production. Farmers should adjust harvest timing and concentrate levels depending on market demand (protein-rich vs. fat-rich milk).

**Future Research Priorities**

1. Future research work should address the residue effects of combined NPS and vermicompost fertilizer on *Urochloa mutica.*
2. On-farm evaluation of combined NPS and vermicompost on *Urochloa mutica* across different agro-ecologies
3. On-farm feeding strategies using *B. mutica*-based diets with concentrate supplementation on different breeds.

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# 8. APPENDIX

## Appendix A. List of Publications

Apependix A1. Gelane Kumssa, Ashenafi Mengistu, Mesfin Dejene, Tekleyohannes Birhanu, Ulfina Galmessa and Teshome Mesfin,

Effect of nutrient management on morphological characteristics, forage productivity, nutritional quality, and economic feasibility of *Urochloa mutica* at Bishoftu, Ethiopia, 2025, *Ethiopian Journal of Agricultural Science*, 35(2), 101-115.

Ethiop. J. Agric. Sci. 35(2) 101-115 (2025)

## Effect of Nutrient Management on Morphological Characteristics, Forage Productivity, Nutritional Quality, and Economic Feasibility of *Urochloa mutica* at Bishoftu, Ethiopia

**Gelane Kumssa[1], Ashenafi Mengistu[2], Mesfin Dejene[1], Tekleyohannes Birhanu[1], Ulfina Galmessa[1] and Teshome Mesfin[1]**

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## Abstract

*A field study was conducted to evaluate the effects of blended NPS fertilizer, vermi-compost, and their combinations on fodder yield, yield components, nutritional quality, and economic feasibility of Urochloa mutica. The experiment was arranged in a randomized complete block design with three replications. Six treatments were applied based on nitrogen equivalency: (T1) control (no fertilizer), (T2) 100% blended NPS, (T3) 100% vermi-compost, (T4) 75% NPS + 25% vermi-compost, (T5) 50% NPS + 50% vermi-compost, and (T6) 25% NPS + 75% vermi-compost. Results showed that T2 (100% NPS) and T4 (75% NPS + 25% vermi-compost) performed comparably across all evaluated parameters, indicating that the combined application of 75% NPS and 25% vermi-compost can fully replace 100% NPS fertilizer. Vermi-compost, being an easily accessible, locally produced organic input, proved to be an ideal amendment, and its combination with NPS fertilizer enhanced the agronomic performance, yield, and quality of Urochloa mutica. The findings suggest that optimal grass productivity in the study area requires improved nutrient management strategies. Therefore, farmers are recommended to adopt either blended NPS alone or the combined application of 75% NPS with 25% vermi-compost for sustainable Urochloa mutica production.*

**Keywords:** NPS fertilizer, Urochloa mutica and Vermi-compost

Appendix A 2. Gelane Kumssa, Ashenafi Mengistu, Mesfin Dejene, Tekleyohannes Birhanu and Ulfina Galmessa,

Morphological characteristics, forage productivity and quality of *Urochloa mutica* as affected by plant spacing and harvesting age, *Ethiopian Journal of Agricultural Sciences*, 2025, 35(2) 53-68.

Ethiop. J. Agric. Sci. 35(2) 53-68 (2025)

# Morphological Characteristics, Forage Productivity and Quality of *Urochloa mutica* as Affected by Plant Spacing and Harvesting Age

**Gelane Kumssa[1], Ashenafi Mengistu[2], Mesfin Dejene[1], Tekleyohannes Birhanu[1] and Ulfina Galmessa[1]**

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## Abstract

*The study was conducted to evaluate the effects of plant spacing and harvesting age on morphological characteristics, yield and chemical composition of Urochloa mutica under supplementary irrigation at Bishoftu Agricultural Research Center, Ethiopia. The experiment contained nine treatments using a plot size of 12m$^2$ (3m*4m) in a factorial layout using RCBD with three replications. The plant intra-row spaces were 20cm, 35cm and 50cm between plants, and harvesting ages were 60, 90 and 120 days. The data collected were plant height (PH), number of tillers per plant (NTPP), number of leaf per plant (NLPP), leaf length per plant (LLPP), number of roots per plant (NRPP), root length per plant (RLPP), leaf to stem ratio (LSR), dry matter yield (DMY) and chemical composition of the forage. All the data were subjected to ANOVA of SAS version 9.0. Results showed that plant spacing and harvesting age had significant ($p<0.05$) effects on morphological characteristics, dry matter yield and chemical composition of Urochloa mutica. All the morphological characteristics studied were higher at later maturity and; except in NRPP, wider and intermediate plant spacing were significantly higher than the narrower. The values for LSR increased with decreasing plant spacing and harvesting age. The TDMY and DM contents were significantly ($p<0.05$) enhanced at narrower plant spacing and advanced maturity. The CP contents were higher at earlier harvesting ages, and the NDF, ADF and ADL values decreased progressively at later stages of harvest. Based on these results, it is concluded that narrow (20cm) plant spacing and late (120 days) harvesting age are optimum for Urochloa mutica production in the study area and other areas having similar agro-ecological conditions.*

Keyword: Chemical compositions, Forage Characteristics, Harvesting age, Plant Spacing and Yield.

**Appendix B. Statical analysis**

**Appendix B1. ANOVA and mean for measured morphological characteristics, yields and nutritional composition of *Urochloa mutica* as affected by fertilizer type.**

| Variables | D.F | Sig. level | Mean |
|---|---|---|---|
| GC (scale) | 5 | ** | 7.9 |
| PH (cm) | 5 | * | 80.0 |
| NTPP | 5 | * | 150.4 |
| NLPP | 5 | * | 1124.4 |
| LLPT (cm) | 5 | * | 25.9 |
| NRPP | 5 | * | 98.5 |
| RLPP (cm) | 5 | * | 15.9 |
| LSR, (ratio) | 5 | * | 2.5 |
| TDMY t/ha | 5 | ** | 14.6 |
| DM (%) | 5 | ** | 90.9 |
| CP (%) | 5 | * | 12.9 |
| Ash (%) | 5 | ** | 10.9 |
| NDF | 5 | ** | 67.5 |
| ADF | 5 | ** | 37.8 |
| ADL | 5 | ** | 7.7 |
| IVDMD (%) | 5 | ** | 58.8 |

GC= Ground cover; PH=Plant Height; NTPP= Number of tillers per plant; NLPP= Number of leaves per plant; LLPT= Leaf length Per Plant; NRPP= Number of Root Per Plant; RLPP=Root Length Per Plant; LSR= Leaf to Stem Ratio; TDMY t/ha= Total Dry matter yield in ton per hectare; DM= dry matter; CP= crude protein, NDF= neutral detergent fiber; ADL= acid detergent fiber; ADL= acid detergent lignin; IVDMD= in vitro dry matter digestibility.

**Appendix B2. ANOVA and mean for measured morphological characteristics, yields and nutritional composition of *Urochloa mutica* planted at different plant spacing and harvested at different age**

| Variables | D.F. | Sig. level | Mean |
|---|---|---|---|
| GC (scale) | 8 | ** | 8.8 |
| PH (cm) | 8 | ** | 96.2 |
| NTPP | 8 | ** | 141.9 |
| NLPP | 8 | ** | 990.1 |
| LLPT, (cm) | 8 | ** | 26.4 |
| NRPP | 8 | ** | 114.2 |
| RLPP, (cm) | 8 | ** | 18.3 |
| LSR (ratio) | 8 | ** | 2.6 |
| TDMY t/ha | 8 | ** | 13.5 |
| TCPY t/ha | 8 | ** | 1.6 |
| Ash (%) | 8 | ** | 10.8 |
| CP (%) | 8 | ** | 12.3 |
| NDF | 8 | ** | 62.1 |
| ADF | 8 | ** | 34.1 |
| ADL | 8 | * | 5.6 |
| IVDMD (%) | 8 | ** | 60.0 |

GC= Ground cover; PH= Plant Height; NTPP= Number of tillers per plant; NLPP= Number of leaves per plant; LLPT= Leaf length Per Plant; NRPP= Number of Root Per Plant; RLPP= Root Length Per Plant; LSR= Leaf to Stem Ratio; TDMY t/ha= Total Dry matter yield ton per hectare; TCPY t/ha= total crude protein yield ton per hectare; CP= crude protein; NDF= neutral detergent fiber; ADF= acid detergent fiber; ADL= acid detergent lignin; IVDMD= in vitro dry matter digestibility.

**Appendix B3. Table of Nutrient intake of cross-bred dairy cows influenced by parities and stage of lactation**

| Variables | N | TDMI | TCPI | TNDFI | TADFI | TADLI |
|---|---|---|---|---|---|---|
| Parity | | | | | | |
| 1 | 28 | $8.8^{b}$ | $1.14^{b}$ | $5.1^{b}$ | $1.97^{b}$ | $1.18^{b}$ |
| 2 | 28 | $9.3^{b}$ | $1.22^{b}$ | $5.4^{b}$ | $2.13^{b}$ | $1.21^{b}$ |
| 3 | 28 | $12.1^{a}$ | $1.69^{a}$ | $6.9^{a}$ | $2.79^{a}$ | $1.33^{a}$ |
| 4 | 28 | $8.8^{b}$ | $1.14^{b}$ | $5.1^{b}$ | $1.97^{b}$ | $1.18^{b}$ |
| Period | | | | | | |
| 1 | 28 | $8.4^{c}$ | $1.12^{c}$ | $4.7^{c}$ | $1.73^{c}$ | 1.14c |
| 2 | 28 | $11.7^{a}$ | $1.32^{b}$ | $5.7^{b}$ | $2.28^{b}$ | $1.24^{b}$ |
| 3 | 28 | $9.9^{b}$ | $1.57^{a}$ | $6.8^{a}$ | $2.82^{a}$ | $1.33^{a}$ |
| 4 | 28 | $9.0^{bc}$ | $1.18^{bc}$ | $5.2^{bc}$ | $2.03^{bc}$ | $1.19^{bc}$ |

Period = stage of lactation; TDMI=total dry matter intake; TCPI= total crude protein intake; TNDFI= total neutral detergent fiber intake; TADFI= total acid detergent fiber intake; TADLI= total acid detergent lignin.

**Appendix B4. Effects of parities and period on metabolizable energy**

| | | ME (MJ/kg) | |
|---|---|---|---|
| Trts | N | Parity | Period |
| T1 | 28 | $6.7^{b}$ | $7.1^{b}$ |
| T2 | 28 | $7.1^{b}$ | $7.2^{b}$ |
| T3 | 28 | $8.4^{ab}$ | $8.1^{ab}$ |
| T4 | 28 | $9.5^{a}$ | $9.1^{a}$ |
| | Mean | 7.9 | 7.9 |

Trts= treatments; ME= metabolizable energy

**Appendix B5. Table of milk yield and composition of cross-bred dairy cows kept on *Urochloa mutica* basal feed with graded level of concentration.**

| Variables | N | TDMY | Fat | Lactose | Protein | Ash | TS | SNF |
|---|---|---|---|---|---|---|---|---|
| Parity | | | | | | | | |
| 1 | 28 | $8.5^{c}$ | $3.8^{a}$ | $5.2^{a}$ | $4.32^{c}$ | $0.69^{a}$ | $12.0^{a}$ | $8.5^{a}$ |
| 2 | 28 | $10.0^{b}$ | $3.7^{a}$ | $5.3^{a}$ | $4.39^{b}$ | $0.68^{a}$ | $12.1^{a}$ | $8.5^{a}$ |
| 3 | 28 | $14.7^{a}$ | $3.8^{a}$ | $5.2^{a}$ | $4.53^{a}$ | $0.70^{a}$ | $11.9^{a}$ | $9.5^{a}$ |
| 4 | 28 | $9.2^{bc}$ | $4.2^{a}$ | $5.3^{a}$ | $4.53^{a}$ | $0.69^{a}$ | $11.9^{a}$ | $8.7^{b}$ |
| Period | | | | | | | | |
| 1 | 28 | $9.6^{c}$ | $3.5^{b}$ | $5.3^{ab}$ | $4.7^{a}$ | $0.7^{a}$ | $10.4^{d}$ | $9.0^{a}$ |
| 2 | 28 | $12.0^{a}$ | $3.6^{b}$ | $5.0^{b}$ | $4.1^{b}$ | $0.7^{a}$ | $11.9^{c}$ | $9.2^{a}$ |
| 3 | 28 | $11.1^{b}$ | $3.6^{b}$ | $5.1^{b}$ | $4.2^{b}$ | $0.7^{a}$ | $12.3^{b}$ | $9.0^{a}$ |
| 4 | 28 | $9.7^{c}$ | $4.3^{a}$ | $5.6^{a}$ | $4.6^{a}$ | $0.7^{a}$ | $13.4^{a}$ | $7.9^{b}$ |
| Mean | | 10.6 | 3.8 | 5.2 | 4.3 | 0.68 | 12.0 | 8.8 |

Trts= treatments; TDMY= total daily milk yield; TS= total solid; SNF= solid not fat

**Appendix B6. The GLM Procedure of Fertilizer Types Experiment**

Class Level Information

| Class | Levels | Values |
|---|---|---|
| Variable | 6 | 0FER 100C 100NPS 25NPS 50NPS 75NPS |

NOTE: All dependent variables are consistent with respect to the presence or absence of missing values. However, only 18 observations can be used in this analysis.

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The GLM Procedure

Dependent Variable: Plant Height (PH)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 5 | 3425.833333 | 685.166667 | 50.55 | <.0001 |
| Error | 12 | 162.666667 | 13.555556 | | |
| Corrected Total | 17 | 3588.500000 | | | |

| R-Square | Coeff Var | Root MSE | PH Mean |
|---|---|---|---|
| 0.954670 | 4.340024 | 3.681787 | 84.83333 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Variable | 5 | 3425.833333 | 685.166667 | 50.55 | <.0001 |

The GLM Procedure

Dependent Variable: Number of Tillers per plant (NTPP)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 5 | 21286.49778 | 4257.29956 | 50.35 | <.0001 |
| Error | 12 | 1014.66667 | 84.55556 | | |
| Corrected Total | 17 | 22301.16444 | | | |

| R-Square | Coeff Var | Root MSE | NTPP Mean |
|---|---|---|---|
| 0.954502 | 6.112163 | 9.195409 | 150.4444 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Variable | 5 | 21286.49778 | 4257.29956 | 50.35 | <.0001 |

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The GLM Procedure

Dependent Variable: Leaves Length Per Plants (LLPP)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 5 | 405.1377778 | 81.0275556 | 48.42 | <.0001 |
| Error | 12 | 20.0800000 | 1.6733333 | | |
| Corrected Total | 17 | 425.2177778 | | | |

| R-Square | Coeff Var | Root MSE | LLPP Mean |
|---|---|---|---|
| 0.952777 | 4.996637 | 1.293574 | 25.88889 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Variable | 5 | 405.1377778 | 81.0275556 | 48.42 | <.0001 |

The GLM Procedure

Dependent Variable: Leaves Length Per Plant (NLPT)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 5 | 1574481.116 | 314896.223 | 29.10 | <.0001 |
| Error | 12 | 129852.822 | 10821.069 | | |
| Corrected Total | 17 | 1704333.939 | | | |

| R-Square | Coeff Var | Root MSE | NLPT Mean |
|---|---|---|---|
| 0.923810 | 9.251179 | 104.0244 | 1124.444 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Variable | 5 | 1574481.116 | 314896.223 | 29.10 | <.0001 |

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The GLM Procedure

Dependent Variable: Number of Roots Per Plants (NRPP)

| Source | DF | Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 5 | 4917.700000 | 983.540000 | 17.63 | <.0001 |
| Error | 12 | 669.600000 | 55.800000 | | |
| Corrected Total | 17 | 5587.300000 | | | |

| R-Square | Coeff Var | Root MSE | NRPP Mean |
|---|---|---|---|
| 0.880157 | 7.583695 | 7.469940 | 98.50000 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Variable | 5 | 4917.700000 | 983.540000 | 17.63 | <.0001 |

The GLM Procedure

Dependent Variable: Roots Length Per Plants (RLPP)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 5 | 181.7138667 | 36.3427733 | 14.28 | 0.0001 |
| Error | 12 | 30.5405333 | 2.5450444 | | |
| Corrected Total | 17 | 212.2544000 | | | |

| R-Square | Coeff Var | Root MSE | RLPP Mean |
|---|---|---|---|
| 0.856114 | 10.01247 | 1.595320 | 15.93333 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Variable | 5 | 181.7138667 | 36.3427733 | 14.28 | 0.0001 |

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The GLM Procedure

Dependent Variable: Leaf to Stem Ratio (LSR)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 5 | 8.89788220 | 1.77957644 | 16.82 | <.0001 |
| Error | 12 | 1.26989312 | 0.10582443 | | |
| Corrected Total | 17 | 10.16777532 | | | |

| R-Square | Coeff Var | Root MSE | LSR Mean |
|---|---|---|---|
| 0.875106 | 11.92946 | 0.325307 | 2.726918 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Variable | 5 | 8.89788220 | 1.77957644 | 16.82 | <.0001 |

The GLM Procedure

Dependent Variable: Dry Matter Yield (DMY t/ha)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 5 | 198.6668944 | 39.7333789 | 25.43 | <.0001 |
| Error | 12 | 18.7470667 | 1.5622556 | | |
| Corrected Total | 17 | 217.4139611 | | | |

| R-Square | Coeff Var | Root MSE | DMY Mean |
|---|---|---|---|
| 0.913772 | 8.553488 | 1.249902 | 14.61278 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Variable | 5 | 198.6668944 | 39.7333789 | 25.43 | <.0001 |

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The GLM Procedure

Dependent Variable: Crude Protein Yield (CPY t/ha)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 5 | 0.91869444 | 0.18373889 | 22.81 | <.0001 |
| Error | 12 | 0.09666667 | 0.00805556 | | |
| Corrected Total | 17 | 1.01536111 | | | |

| R-Square | Coeff Var | Root MSE | CPY Mean |
|---|---|---|---|
| 0.904796 | 5.932976 | 0.089753 | 1.512778 |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Variable | 5 | 0.91869444 | 0.18373889 | 22.81 | <.0001 |

**Appendix B7. The GLM Procedure of Plant Spacing and Harvesting Age**

Class Level Information

| Class | Levels | Values |
|---|---|---|
| TRT | 9 | T1 T2 T3 T4 T5 T6 T7 T8 T9 |
| Space | 3 | 20 35 50 |
| HD | 3 | 60 90 120 |

The GLM Procedure

Dependent Variable: Plant Height

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 8 | 2625.290359 | 328.161295 | 5.54 | 0.0012 |
| Error | 18 | 1065.620363 | 59.201131 | | |
| Corrected Total | 26 | 3690.910722 | | | |

| R-Square | Coeff Var | Root MSE | Height Mean |
|---|---|---|---|
| 0.711285 | 8.002029 | 7.694227 | 96.15346 |

The GLM Procedure

Dependent Variable: Number of Tillers Per Plants (NTPP)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 8 | 7661.148477 | 957.643560 | 7.99 | 0.0001 |
| Error | 18 | 2157.297037 | 119.849835 | | |
| Corrected Total | 26 | 9818.445514 | | | |

| R-Square | Coeff Var | Root MSE | NTPP Mean |
|---|---|---|---|
| 0.780281 | 7.713262 | 10.94759 | 141.9321 |

The GLM Procedure

Dependent Variable: Number of Leaves Per Plants (NLPP)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 8 | 216038.5331 | 27004.8166 | 7.83 | 0.0002 |
| Error | 18 | 62042.1457 | 3446.7859 | | |
| Corrected Total | 26 | 278080.6789 | | | |

| R-Square | Coeff Var | Root MSE | NLPP Mean |
|---|---|---|---|
| 0.776892 | 5.929456 | 58.70933 | 990.1301 |

The GLM Procedure

Dependent Variable: Leaves Length Per Plants (LLPP)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 8 | 207.6976132 | 25.9622016 | 21.24 | <.0001 |
| Error | 18 | 22.0014815 | 1.2223045 | | |
| Corrected Total | 26 | 229.6990947 | | | |

| R-Square | Coeff Var | Root MSE | LLPP Mean |
|---|---|---|---|
| 0.904216 | 4.194468 | 1.105579 | 26.35802 |

The GLM Procedure

Dependent Variable: Roots Length Per Plants (RLPP)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 8 | 160.6488000 | 20.0811000 | 10.12 | <.0001 |
| Error | 18 | 35.7192000 | 1.9844000 | | |
| Corrected Total | 26 | 196.3680000 | | | |

| R-Square | Coeff Var | Root MSE | RLPP Mean |
|---|---|---|---|
| 0.818101 | 7.706167 | 1.408687 | 18.28000 |

The GLM Procedure

Dependent Variable: Dry Matter Yield (DMY t/ha)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 8 | 59.42140000 | 7.42767500 | 7.68 | 0.0002 |
| Error | 18 | 17.41226667 | 0.96734815 | | |
| Corrected Total | 26 | 76.83366667 | | | |

| R-Square | Coeff Var | Root MSE | DMY t/ha Mean |
|---|---|---|---|
| 0.773377 | 7.257397 | 0.983539 | 13.55222 |

The GLM Procedure

Dependent Variable: Leaf to Stem Ratio LSR

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 8 | 2.50418519 | 0.31302315 | 2.64 | 0.0417 |
| Error | 18 | 2.13653333 | 0.11869630 | | |
| Corrected Total | 26 | 4.64071852 | | | |

| R-Square | Coeff Var | Root MSE | LSR Mean |
|---|---|---|---|
| 0.539612 | 13.21325 | 0.344523 | 2.607407 |

The GLM Procedure

Dependent Variable: Crude Protein Yield (CPY)

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | 8 | 0.46665415 | 0.05833177 | 2.66 | 0.0406 |
| Error | 18 | 0.39524237 | 0.02195791 | | |
| Corrected Total | 26 | 0.86189652 | | | |

| R-Square | Coeff Var | Root MSE | CPY Mean |
|---|---|---|---|
| 0.541427 | 8.954622 | 0.148182 | 1.654810 |

**Appendix C. Pictures during the research work**