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Assessment of Forage Production and Utilization Practices and Evaluation of Morphological Characteristics, Biomass Yield, and Feeding Value of Mulato II and Desmodium intortum for Ram

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BAHIR DAR UNIVERSITY

College of Agriculture and Environmental Sciences

Department of Animal Sciences

**Assessment of Forage Production and Utilization Practices and
Evaluation of Morphological Characteristics, Biomass Yield, and
Feeding Value of Mulato II and *Desmodium intortum* for Rams**

PhD Dissertation

By

Muluye Fekade Asinakew

**July, 2025
Bahir Dar, Ethiopia**

BAHIR DAR UNIVERSITY
College of Agriculture and Environmental Sciences
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Evaluation of Morphological Characteristics, Biomass Yield, and
Feeding Value of Mulato II and *Desmodium intortum* for Rams**

By

Muluye Fekade Asinakew

A Dissertation Submitted in Partial Fulfillment of the Requirements for the
Degree of Doctor of Philosophy (PhD) in Animal Nutrition

Advisory Board Members

Yeshambel Mekuriaw (PhD, Professor; Principal advisor)

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July, 2025
Bahir Dar, Ethiopia

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DECLARATION

This is to certify that the dissertation entitled “**Assessment of Forage Production and Utilization Practices and Evaluation of Morphological Characteristics, Biomass Yield, and Feeding Value of Mulato II and *Desmodium intortum* for Rams**”, submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy/PhD in Animal Nutrition to the Department of Graduate Council of Animal Sciences, Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University, is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during the course of this investigation have been duly acknowledged.

Muluye Fekade Asinakew



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Approval of Dissertation

I hereby certify that I have supervised, read, and evaluated this dissertation titled **"Assessment of Forage Production and Utilization Practices and Evaluation of Morphological Characteristics, Biomass Yield, and Feeding Value of Mulato II and *Desmodium intortum* for Rams"** by Muluye Fekade Asinakew prepared under my guidance. I recommend the dissertation be submitted for oral defense.

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Approval of Dissertation for Defense Result

As members of the board of examiners, we examined this dissertation titled “**Assessment of Forage Production and Utilization Practices and Evaluation of Morphological Characteristics, Biomass Yield, and Feeding Value of Mulato II and *Desmodium intortum* for Rams**” by Muluye Fekade Asinakew. We hereby certify that the dissertation is accepted for fulfilling the requirements for the award of “Doctor of Philosophy in Animal Nutrition”.

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DEDICATION

To my beloved mother, Tsehay Teshale Abraham.

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Assessment of Forage Production and Utilization Practices and Evaluation of Morphological Characteristics, Biomass Yield, and Feeding Value of Mulato II and *Desmodium intortum* for Rams

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ABSTRACT

The use of forages plays utmost role in averting the current livestock feed gap. The study aimed to assess forage production and utilization practices and evaluation of morphological characteristics, biomass yield, and feeding value of Mulato II and *Desmodium intortum* for rams. The study involved a multifaceted activity which include survey, agronomic, and animal evaluation experiments. For the survey activity, two districts namely, Kalu and Dawa Chefa with a total of 180 respondents, 90 respondents from each district, were purposively selected based on push-pull technology practice and livestock production potentials. Randomized complete block design (RCBD) in a factorial arrangement with three factors, planting pattern (sole Mulato II, sole *D. intortum* and intercropped Mulato II with *D. intortum*), agroecologies (lowland and midland) and harvesting ages (90 and 120 days), was used for the agronomic experiment. The morphological characteristics measured were plant height (PHPP), number of tiller (NTPP), number of leaf (NLPP), leaf length (LLPP), leaf to stem ratio (LSR), root length (LRPP), number of roots (NRPP) for Mulato II, number of branches (NBPP) and number of root nodule (NRNPP) for *D. intortum* and land equivalent ratio (LER). The chemical composition parameters analyzed were Ash, CP, NDF, ADF, and ADL. Dry matter yield (DMY t/ha), Crude protein yield (CPY t/ha), IVDMD (%) and ME (MJ/kg DM) were also determined. Twenty-five yearling Farta rams were blocked based on their initial body weight (18 ± 1.36 kg) (mean $\pm$ SD) and randomly assigned into the five treatment

diets in a RCBD to examine their growth performance for a period of 90 days excluding 15 days of adaptation. The treatments were T1 (NPH *ad libitum*+ concentrate only), T2 (natural pasture hay (NPH) *ad libitum*+ 80% concentrate+ 20% Mulato II and *D. intortum*), T3 (NPH *ad libitum*+ 60% concentrate +40% Mulato II and *D. intortum*), T4 (NPH *ad libitum*+ 40% concentrate+ 60% Mulato II and *D. intortum*), and T5 (NPH *ad libitum*+ 20% concentrate +80% Mulato II and *D. intortum*). The concentrate comprised of noug seed cake, wheat bran, and ground maize grain. The five treatments were made in such a way that the concentrate mix was progressively replaced by Mulato II and *D. intortum* forages at a proportion of 0, 20, 40, 60, and 80% on DM basis. Besides, the data on blood profiles and enteric methane emission was collected from all the experimental sheep. The data on blood hematology test (RBC, WBC, PLAT, Hag, HCT, MCV, MCH, and MCHC) was done using automated hematological analyser. Blood biochemical parameters (blood glucose, Total protein, Albumin, Urea nitrogen and Total cholesterol) was done using automated biochemical analyser. Enteric methane emission of sheep was measured using portable hand-held laser methane detector (LMD). The data for the survey was analyzed using SPSS version 26, while the GLM procedure of SAS version 9.4 was used for the agronomic and animal evaluation experiments. The result revealed that the majority of respondents (58.9 and 74.4%) have experience in the production of Mulato II and *D. intortum* in Kalu and Dawa Chefa districts, respectively. Most of the farmers (63.3 and 74.4%) used cut and carry system to feed their livestock in Kalu and Dawa Chefa districts, respectively. Mulato II and *D. intortum* were used as crop pest control (Mulato II an attractive trap plant and *D. intortum* as a repellent) and livestock feed in both study areas. Land scarcity, shortage of planting materials, and lack of awareness were the major impediments for production. The field experiment showed that, except land equivalent ratio (LER), most morphological characteristics (PHPP, NTPP, NLPP, LLPP, LSR, NRPP, LRPP, NBPP, and NRNPP) were significantly affected ($P<0.05$) by the interaction effect of planting pattern, agroecologies, and harvesting ages. Similarly, the Ash, CP, NDF for Mulato II, ADF, ADL for Mulato II, and IVDMD values were significantly ($P<0.05$) affected by the interaction effect except NDF and ADL for *D. intortum* and metabolizable energy (ME) for both Mulato II and *D. intortum*. The highest

CP content (12.3%) was recorded from the intercropped Mulato II with *D. intortum* at 90 days of harvesting time in the lowland agroecology. The highest dry matter yield (DMY) (17.04 and 16.7 t/ha) was obtained from both intercropped Mulato II and *D. intortum*, respectively, harvested at 120 days in the lowland agroecology. Optimum DMY and CP value of Mulato II and *D. intortum* were obtained from the intercrop, harvested at 120 days in the lowland agroecology. The feeding trial showed that total dry matter intake, average daily gain, and feed conversion efficiency of sheep were not affected by the substitution of concentrate with Mulato II and *D. intortum* mixed forages. In addition, all the blood profiles tested were not affected by the substitution effect of the supplemental forages ($P>0.05$) except for red blood cell (RBC) and all the blood variables tested were within the recommended ranges for a healthy sheep. Furthermore, enteric methane emission of the sheep was not varied ($P>0.05$). In conclusion, the appreciable quantity and quality of Mulato II and *D. intortum* forages observed could suggest those forages are good alternative and equally important to potentially substitute the concentrate in the diet of sheep without any negative effect on intake, digestibility, and ADG, health and environment.

Keywords: Agronomic performance, Blood profile, Grass, Growth performance, Legume, Methane emission, Quality

ABBREVIATIONS AND ACRONYMS

ADG	Average Daily Gain
ADL	Acid Detergent Lignin
ADF	Acid Detergent Fiber
ANOVA	Analysis of Variance
AOAC	Associations of Official Analytical Chemists
ARC	Agricultural Research Council
BW	Body Weight
CP	Crude Protein
CPY	Crude Protein Yield
CSA	Central Statistics Agency
DM	Dry Matter
DMY	Dry Matter Yield
EDTA	Ethylene Diamine Tetra Acetic Acid
FAO	Food and Agriculture Organization of the United Nations
FCE	Feed Conversion Efficiency
GLM	General Linear Model
ILRI	International Livestock Research Institute
IVDMD	<i>In vitro</i> Dry Matter Digestibility
M.A.S. L	Meter Above Sea Level
MCHC	Mean Corpuscular Hemoglobin Concentration
MCV	Mean Corpuscular Volume
ME	Metabolizable Energy
MJ	Mega Joule
MoANR	Ministry of Agriculture and Natural Resources of Ethiopia
LLPP	Leaf Length Per Plant
LMD	Laser Methane Detector
LSR	Leaf to Stem Ratio
NDF	Neutral Detergent Fiber

ABBREVIATIONS AND ACRONYMS (Continued)

NLPP	Number of Leaves Per Plant
NPH	Natural Pasture Hay
NRC	National Research Council
NRPP	Number of Roots Per Plant
NSC	Noug Seed Cake
OM	Organic Matter
OMD	Organic Matter Digestibility
PCV	Packed Cell Volume
PPT	Push-pull Technology
RBC	Red Blood Cell
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
SD	Standard Deviation
SE	Standard Error
TLU	Tropical Livestock Unit

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CHAPTER 1: GENERAL INTRODUCTION

1.1. Background

Ethiopia is an agricultural country where more than 85% of the population resides in rural areas and it is the home of largest livestock population in Africa (CSA, 2021). Livestock are an integral part of the livelihoods of millions of people in Ethiopia and will remain important in the coming decades (Duguma and Janssens, 2021; Assefa *et al.*, 2024). The sector contributes about 17-25.3% of the GDP and 39-49% of the agricultural GDP (including the non-monetary values) and over 50% of household incomes (Shapiro *et al.*, 2017; Bachewe *et al.*, 2018). They are a key provider of animal protein, supply power for cultivating crops, and function as a mode of transportation. Additionally, they contribute as valuable export goods, deliver manure for fertilizing fields and energy for households, offer a safety net during periods of crop failure, and act as a method for building wealth (Mekuriaw and Harris-Coble, 2021). Moreover, the role of livestock in Ethiopia is becoming more important over time. The demand for human foods of animal origin is increasing because of the drivers such as population growth, rise in per capita incomes, and urbanization (Duguma and Janssens, 2021).

Ethiopia has a large number of small ruminant populations which is estimated at 42.9 million sheep and 52.50 million goats (CSA, 2021). These animals are reared with different production systems and widely adapted to different agroecological zones of the country. They are among the major economically important livestock and contribute significantly to the livelihood of resource-poor farmers with multiple functions (Sheriff and Alemayehu, 2018). Because of great adaptability to difficult environmental conditions and to diverse diets, they have long been considered very useful animals for their good productivity, and low risk. Additionally, their feed requirements are often better suited to the farming systems, making them more efficient (Akinmoladun *et al.*, 2019).

Despite the huge livestock number, manifold roles and existing favorable environmental conditions, their productivity is far below their potential (Getabalew *et al.*, 2019; Tegegne and Legese, 2020; Dinkissa and Guye, 2022). They are unable to meet the

demands for the rapidly growing human population in foreseeable future (Shapiro *et al.*, 2015; Mengesha, 2023). Likewise, its contribution to nutrition and export earning of the country is disproportionately low due to poor productivity of the animals (Shapiro *et al.*, 2017). Amongst others, feed shortage both in quality and quantity is the major hindering factor for such poor productivity of livestock (Assefa *et al.*, 2013; Mengistu, 2018).

Obviously, the common livestock feed resources in Ethiopia are natural pasture, crop residues, improved feed, hay, agroindustrial byproducts, and others (CSA, 2021). Though natural pasture and crop residues are the major feed resource in the country (CSA, 2021), they cannot support beyond the maintenance requirement of the animals (Astbha *et al.*, 2020) owing to the lower content of digestible nutrients (Gebremariam and Belay, 2021; Gemiyo, 2015); requiring supplementation with quality feeds for sustainable livestock production. In spite of forage research and development efforts carried out in the country for the last five decades, the contribution of improved forages as a livestock feed is insignificant (Tesfaye and Tessema, 2023). Farmers' knowledge on the production of improved forages, plantation material and land shortage were often reported as major reasons for such a problem (Gashe, 2022; Tesfaye and Tessema, 2023). The inadequate availability coupled with the high price of concentrate feeds are also becoming more challenging for the majority of the livestock producers. The ingredient for concentrate feed is a cereal grain and at the same time it is also a major staple food for the increasing human population and this could create high competition and high price now and the years to come.

Consequently, looking for improved forages containing both grass and legumes together could be a promising approach in availing sufficient and quality forage in the production system. Grass-legume mixture cultivation would also serve in degraded land rehabilitation (Dhakal and Islam, 2018). This makes the environment more sustainable and pave way to climate resilient options offering potential for increasing herbage accumulation (Gulwa *et al.*, 2017). Furthermore, forages are certainly known as a cost-effective feed as compared to commercial concentrates (Gelayenew *et al.*, 2020). The exploitation of green forage or fodder that is rich in nutrients and having a high dry

matter intake, digestibility, and low fiber content, would help to lower the cost of livestock feeding (Mahanta *et al.*, 2020).

Brachiaria grass is among the potential forage species that could play an important role in providing realistic options toward quality and quantitative forage production (Mwendia *et al.*, 2022; Tarekegn *et al.*, 2023). Brachiaria hybrid cultivars have shown promising results in improving livestock productivity as they have been bred for quality and biomass production (Maina *et al.*, 2020). The grass has also been promoted as climate smart (Mundia, 2021). The grass is regarded as climate smart since it is highly valued in reducing methane emission, high herbage yield, and increase productivity of animals (Mwendia *et al.*, 2022). Several scholars evaluated the agronomic and chemical composition of Mulato II in Ethiopia (Tadesse *et al.*, 2021; Worku *et al.*, 2021). The nutritional value of the grass was also evaluated in sheep and resulted in appreciable results (Adnew *et al.*, 2021).

In recent years, Cheruiyot *et al.* (2020) and Maina *et al.* (2020) pointed out that, Brachiaria grass species have been introduced and cultivated by many farmers in eastern Africa. The use of Brachiaria hybrid grass for forage production has been reported in Ethiopian highlands (Worku *et al.*, 2021). In addition to their adaptability to various agroecological conditions and soil types, their deep root systems allow them to efficiently absorb nutrients and moisture. They produce high biomass yields and offer valuable nutrition to livestock. These plants also play a key role in mitigating climate change impacts, serve as effective bioagents for pest and parasitic weed control and are capable of withstanding dry periods in tropical regions (Maass *et al.*, 2015; Khan *et al.*, 2014).

However, grasses in general are known to have low crude protein that cannot solely sustain ruminant animals compared to the legumes. Hence, forage production schemes such as intercropping grasses with forage legumes play utmost role to bridge the nutritional gap. The advantages of grass- legume pasture outweigh pure stand forages and tend to give higher yield than sole crops, greater yield stability and efficient use of nutrients (Kocer and Albayrak, 2012). Growing grass alone would have less protein than intercropped/mixed with legumes (Brown *et al.*, 2018). Gelayenew *et al.* (2020) reported that Napier grass intercropped with vetch had higher protein compared to the sole crop.

Sufficient forage protein from potential intercrops could cut the need for protein supplementation to ruminants and other associated costs (Omokanye *et al.*, 2020). In light of this, higher dry matter yields were reported with vetch and desho grass intercropping at different harvesting stage (Tesfaye, 2019). The higher productivity of forage under grass–legume intercropping systems has also been well established in Ethiopia (Menbere *et al.*, 2015; Hassen *et al.*, 2017; Demlew *et al.*, 2019). In an experiment with animals, grasses and legumes mixture has shown an improvement in animal productivity (Santos *et al.*, 2022). But, limited information has been documented about the planting pattern of Mulato II and *D. intortum* in Ethiopia. Sorting out the best grass-legume combination would enrich the establishment of more productive crop-livestock integration systems (Santos *et al.*, 2022). *Desmodium intortum* is among the tropical legumes that could be suited for intercropping with potential forage grasses (Heuzé *et al.*, 2017). It is noted that *D. intortum* gives more DM yield and nutrient value in intercropping regimes compared to most legumes (Maitra *et al.*, 2021). It is a large, perennial, and fast-growing tropical forage legume. This forage legume provides good ground cover in 4-5 months, and compatible to a variety of soils, and grows well on acidic soils (Mutwedu *et al.*, 2020).

The performance of animals, whether it is aimed at producing meat or milk, depends upon the animal's potential for production and the quantity and quality of forages consumed (Kumar *et al.*, 2018). In turn, forage quality is affected by various factors such as crop species and planting pattern (Santos *et al.*, 2022), maturity stage (Zhang *et al.*, 2018) and environment (Guyader *et al.*, 2018). The extent to which these factors affect the productivity and nutritive value of Mulato II and *D. intortum* forages is not yet investigated in Ethiopia. On top of this, evaluation of these forages in relation to the health of animals and environment is not studied. Therefore, assessing forage production and utilization practices and evaluation of the effect of planting pattern (sole Mulato II, sole *D. intortum*, and intercropped Mulato II with *D. intortum*), agroecologies (low and midland), and harvesting ages (90 and 120 days) on the morphological characteristics, herbage yield, nutritive and supplementary value of Mulato II and *D. intortum* to cope with the existing feed related constraint worth much attention. This contributes to understanding of the factors which influences the yield and nutritional potential of those

forages and the effect of those forages on the health and environment. Subsequently, this package of different activities could help to fully utilize the forages as livestock feed.

1.2. Statement of the Problem

Feed scarcity is a critical problem that hinders the livestock sector in Ethiopia (Gebreyohannes *et al.*, 2021). In Ethiopia, natural pasture and crop residues are seasonal, low in quantity and quality (Mengistu *et al.*, 2017a). This calls for alternative ways of forage production and utilization. To this end, assessing forage production and utilization practices and sorting out the barriers is important to tackle the challenge. One of the attempts to avert the existing feed shortage is the use of multipurpose forages as livestock feed. In this regard, the cultivation of improved forages plays a great role in the production of sufficient and quality feeds for livestock. Although their contribution has remained very limited, improved forages were introduced to Ethiopia long time ago (Mengistu *et al.*, 2017b; Tesfaye and Tessema, 2023). The natural pasture of the country is less productive and requiring intervention. The better way to improve the feeding value of this tropical pasture is through improved forage development using strategies such as intercropping the grass with the forage legumes (Ojo *et al.*, 2013). Grass-legume intercropping has a tremendous advantage to improve soil fertility, forage yield and nutritional quality, and suppress weed infestation (Rusdy, 2021). In addition, grass-legume intercropping is an environmentally friendly forage production strategy which decreases greenhouse gas emissions (Ghani *et al.*, 2022).

Brachiaria hybrid grass and *D.intortum* are among the available forages with a multitude of functions as a potential animal feed and environmental protection. These forages are increasingly acknowledged due to less resource demanding, high productivity and multipurpose forage, and adaptable to different agroecological conditions. Brachiaria hybrid grass is one of the potential cultivated forages that is highly valued in terms of its wide adaptability to different agroecologies, resistance to pest, and productivity in many parts of the tropics (Maina *et al.*, 2020). Brachiaria hybrid grass and *D. intortum* were promoted by Lives Project and Wollo University in Eastern Amhara, Ethiopia. Their introduction is mainly associated with the practice of push-pull technology (PPT) to control crop pests (Dejen, 2014) since the technology uses a repellent intercrop,

Desmodium spp. and an attractive trap plant, Mulato II. Besides, the system also provides quality animal fodder (Ogot *et al.*, 2018).

However, studies about *Brachiaria* hybrid cultivars such as Mulato II in Ethiopia were restricted in locations and focused on the potential value of the grass particularly in pure stand without considering intercropping with legumes such as *D.intortum* (Adnew *et al.*, 2018; Worku, *et al.*, 2021). As a result, information regarding planting pattern (intercropping, and pure stand) associated with Mulato II and *D. intortum* forages is generally lacking which otherwise has numerous advantages. Consequently, the effect of planting pattern, agroecologies, and harvesting ages on the productive and nutritive potential of those forages is not yet investigated. In addition, there has been no comprehensive information made to investigate forage production and utilization practices, yield and feeding potential of the Mulato II and *D.intortum* in Ethiopia. Hence, it is imperative to assess forage production and utilization practices, and evaluate the effects of planting pattern, agroecologies, and harvesting ages on the yield, nutritive and supplementary value of Mulato II and *D.intortum* forages in Ethiopia. Furthermore, Korir *et al.* (2022) the effect of replacing brachiaria hay with either *D. intortum* or dairy concentrate on enteric methane emission. But, information on the blood profiles and enteric methane emission of animals supplemented with Mulato II and *D. intortum* mixed forages is not available. This dissertation was then conducted based on the following research objectives.

1.3. General Objective

The general objective of this dissertation was assessment of forage production and utilization practices and evaluation of morphological characteristics, biomass yield, and feeding value of Mulato II and *Desmodium intortum* for rams.

1.3.1. Specific objectives

This dissertation had the following specific objectives:

- To assess the production and utilization practices of Mulato II and *D. intortum* forages in eastern Amhara region, Ethiopia.

- To evaluate the effects of planting pattern, agroecologies and harvesting ages on the morphological characteristics, yield and nutritive value of Mulato II and *D. intortum* forages.
- To evaluate the substitution effect of Mulato II and *D. intortum* mixed forage for concentrate on feed intake, digestibility, and body weight gain of yearling rams fed natural pasture hay basal diet.
- To evaluate the replacement value of Mulato II and *D. intortum* mixed forage for concentrate on blood profiles and enteric methane emission of yearling rams fed natural pasture hay basal diet.

CHAPTER 2: LITERATURE REVIEW

2.1. Overview of Feed Resources Availability and Utilization in Ethiopia

There are different types of feed resources utilized by livestock in Ethiopia. Among the various feed resources, natural pasture, crop residues, improved forage, hay, agroindustrial by products, and others are accounting for 54.54, 31.13, 0.57, 7.35, 2.03, and 4.37%, respectively (CSA, 2021). Despite its decline in coverage, natural pasture remains the primary livestock feed resource available in Ethiopia (CSA, 2021; Tesfaye and Tessema, 2023). According to FAO, (2018), the total annual biomass available for animal feeding in Ethiopia is estimated at 144.48 million tons, containing approximately 890×10^9 MJ of metabolizable energy (ME) and 7.49 million tons of crude protein (CP). Forages contribute significantly, accounting for 96.6% of the total ME and 92% of the total CP availability. At present, the role of natural pasture as a major livestock feed resource is diminishing from time to time due to high population growth that led conversion of pasture lands into crop lands (Mekasha *et al.*, 2014; Gizaw *et al.*, 2017). For instance, the natural pasture coverage in 2015 was 56.23% (CSA, 2015), but in 2021, its coverage declined to 54.54% (CSA, 2021). Consequently, available pasture lands are highly fragmented and restricted to areas where conditions are hostile for cropping due to topographic, edaphic and climatic factors in the highlands (Feyissa *et al.*, 2013). Besides, the natural pasture in Ethiopia is characterized by seasonal fluctuation in total dry matter (DM) production and nutritional quality (Gurmessa, 2021). The adverse effect of soil fertility depletions coupled with climate change on the composition of native pasture species resulted in less palatable species to dominate (Bezabih *et al.*, 2014; Tamou, 2017).

In addition to the natural pastures, crop residues have for a long time been a major source of feed for animals and will continue to be so for the foreseeable future (Avadhanam *et al.*, 2020). Crop residues are harvested byproducts that include various types of straws and chaff of cereals and pulses in general (CSA, 2021). With expansion of arable land and resultant decline in grazing resources, nowadays, the role of crop residue is booming and is becoming an increasingly important component of livestock

feeds (CSA, 2015; Duncan *et al.*, 2016). Crop residues are abundantly available at the beginning of the dry season following the harvest and threshing of cereal and pulse crops (Birhan and Adugna, 2014) and thus, are main dry season feed resources (Gashe and Kassa, 2018; Assefa *et al.*, 2022). These feed resources are characterized by low nitrogen, energy, mineral, and vitamin contents (Chalchissa *et al.*, 2014). This could impact the rumen ecology by suppressing the amount of protein and energy reaching the rumen. In this regard, using processing techniques such chopping, soaking and urea treatments of such feeds to enhance their nutritive potential has been reported in earlier study (Gurmessa *et al.*, 2016). Enhancing rumen microbial protein has significant importance in the enhancement of animal performance since ruminants meet their nitrogen requirements through microbial protein synthesis (Lu *et al.*, 2019). Obviously, ruminants depend on poor quality roughages which constitute the principal source of feed and unable to get sufficient nutrients to express their full potential.

In spite of its varied availability across regions and districts, agroindustrial byproducts are also used for livestock feeding (Gizaw *et al.*, 2017). In fact, the supply of processed animal feedstuffs is very limited in Ethiopia (Feyissa *et al.*, 2015). In respect to this, agroindustrial byproducts are highly valued in feeding livestock mainly in urban and periurban livestock production system (Tonamo *et al.*, 2015). Agroindustrial byproducts are feed resources that include oil cakes, bran and brewery residues (CSA, 2021). These byproducts can provide alternative sources of energy, protein, soluble fiber or less digestible roughage (García-Rodríguez *et al.*, 2019). A total of 918,648 and 345,974 tons of cereal brans and oil seed cakes are produced in Ethiopia annually, respectively (Feyisa *et al.*, 2024). However, the utilization practice of agroindustrial byproducts such as noug seed cake is limited due to high cost and inaccessible for remotely residing smallholder farmers (Tesfay and Tesfay, 2013; Beyene *et al.*, 2020).

The other feed resource for livestock is browse species. These feed resources can be used as an alternate feed to compensate for nutrient deficiencies and feed shortages especially during dry periods (Mlambo *et al.*, 2016; Mnisi and Mlambo, 2017). Most of the browse species are semi deciduous and/or ever green throughout the year compared to the grasses that become wilted or dried during the dry season (Gebru *et al.*, 2018). On top

of their existence for long periods as green, they are also endowed with high nutrient content (Habib *et al.*, 2016) and most tropical browse species contain reasonably high crude protein with low fiber contents (Gemed and Hassen, 2015). Overall, use of affordable feed resources particularly grass and legume forages worth a greater advantage compared to the less accessible and skyrocketed prices of such concentrate feeds as well as low quality natural pastures and crop residues to increase the productivity of farm animals and profitability of farmers.

Nowadays, improved forages also have got increasing interest and recommended to be used as livestock feed by animal nutritionists in Ethiopia. Improved forages such as forage legumes play a significant role in nitrogen fixation; have high crude protein in the leaves and foliage, which can be used as a protein supplement for livestock (Lukuyu *et al.*, 2012). Improved forages are also less costly compared to purchasing concentrates and agroindustrial byproduct feeds. The cultivation and utilization of improved forages are considered to be environmentally friendly (Assefa, 2012). Despite these facts, improved forages production are constrained by many challenges like small land holdings, lack of forage seeds, and limited knowledge on forage species and their production systems (Salo *et al.*, 2017; Mengistu *et al.*, 2021a; Mijena, 2022). Improved forages are utilized in different ways. For example, it is reported that farmers used cut and carry feeding system to feed their animals. Besides, conserving improved forages for later use is very limited in most parts of Ethiopia due to the low biomass yield (Zeru and Lijalem, 2016).

2.2. Variables Influencing Forage Yield and Quality

Higher forage yield and fodder quality are of great importance for sustainable livestock production (Glamoclija *et al.*, 2011). However, there are various factors that influence the yield and quality of forages. Both quality and quantity of forages are affected significantly due to variations in species, stage of growth, and agronomic practices (Rai, 2024). As a result, several studies have been conducted to evaluate the yield and quality of different forages upon different factors (Hassen *et al.*, 2017; Adnew *et al.*, 2018; Tesfaye, 2019; Tezera *et al.*, 2024) so as to bridge the livestock feed gap.

Thus, the effect of some of the factors on forage herbage yield, morphological characteristics, and nutritional values are indicated in the following sections.

2.2.1. Harvesting ages

Fodder quality and higher forage yield are the major variables of great interest by livestock farmers. Maturity stage at harvest is the most important factor that affects forage quality and yield (Habte *et al.*, 2020). Forage quality decreases with advancing maturity which in turn affects forage digestibility and consumption by animals due to high fiber concentration (Moore *et al.*, 2020).

Information related to the effect of harvesting stage on morphological characteristics such as plant height, tiller number, and leaf length is evident (Tesfaye, 2019; Adnew *et al.*, 2019; Msiza *et al.*, 2021). The plant height is the shortest distance between the soil surface and the upper portion of the seed head (Ozkose and Tamkoc, 2014). Plant height matters because of its ability to acquire more sunlight which later improves the process of photosynthesis (Msiza *et al.*, 2021). Bantihun *et al.* (2022) and Zemene *et al.* (2020) observed an increase in plant height in the latter stages of harvesting for *Brachiaria mutica* grass. The general progressive increase in plant height might be associated with massive root development and efficient nutrient uptake, allowing the plant to continue to increase in height. Harvesting ages also significantly affect the number of leaves per plant (Tilahun *et al.*, 2017; Asmare *et al.*, 2017). Supporting this finding, an increase in the number of leaves per plant of *Brachiaria mutica* grass was reported in Bahir Dar as harvesting age increased from 60 to 120 days (Zemene *et al.*, 2020).

The other morphological characteristic influenced by harvesting ages is number of tillers per plant. Tillers density is an important attribute of grasses. Tillering performance is an indicator of herbage yield. Higher tiller production is associated with both sustained productivity and enhanced resilience under challenging environmental conditions (Poirier *et al.*, 2012). According to Zemene *et al.*, 2020), maximum number of tiller (67.4) was recorded at the late harvesting age (120 days). This is in agreement with the finding of Tilahun *et al.* (2017) who observed that mean tiller number per plant increased from 36.4

to 106.4 at 75 and 135 harvesting ages, respectively. A progressive increase in tiller number was also observed with delayed harvesting time (Adnew *et al.*, 2018).

Harvesting ages not only affects morphological characteristics, but also the dry matter yield of the forages. Accordingly, the general trend in total dry matter yield increments as harvesting age prolonged was reported in previous studies (Turk and Albayrak, 2012; Wanania, 2019). A study in the highlands of Ethiopia also indicated that dry matter yield of desho grass increased as harvesting dates delayed (Mijena *et al.*, 2023). In line with this observation, the total DM increased progressively from 7.1 to 25.5 t/ha at 75 and 135 days of harvesting time (Tilahun *et al.*, 2017).

Likewise, harvesting time is also the most critical factor affecting forage quality. Accordingly, with delayed harvesting ages, a reduction in nutritive value of the grass was reported (Wanania, 2019). According to Alstrup *et al.* (2016), lower concentration of NDF and high digestible forage were obtained at an early maturity cuts as compared to the late maturity cuts. Similarly, as the stage of harvesting increased, CP content of forages decreased due to the maturation of the grass (McIntosh *et al.*, 2016). In accordance to this finding, CP content of buffle grass decreased from 13.57 to 6.72% at 60 and 120 harvesting days (Wanania, 2019). The same author argued that, the decline in CP content with advancing maturity might be due to an increase in structural carbohydrate and lignin contents of forage materials and reduced leaf to stem ratio. In contrast, fiber contents such as NDF, ADF, and lignin tended to increase with delayed harvesting time (Alstrup *et al.*, 2016; Jagadeesh *et al.*, 2017; Elgersma and Søegaard, 2018). Furthermore, mineral contents of forages such as P, Ca, Mg and K declined with delayed harvesting and thus, its quality (Turk and Albayrak, 2012).

2.2.2. Planting pattern

The planting pattern is crucial for achieving optimal quality and biomass, one effective approach being the use of intercropping grasses with legumes. Intercropping is a cropping system which involves cultivating two or more crops in the same space (Mousavi and Eskandari, 2011; Altieri *et al.*, 2012; Dowling *et al.*, 2021). Intercropping boosts animal production through enhancing the quality and quantity of the forages (Atienza and Rubiales, 2017). Besides, intercropping, as a means of agricultural

intensification, has proved to be a vital practice in increasing land use efficiency and thus, uplifting the yield gain and increasing the economic value of the agricultural system (Salama *et al.*, 2022). Forage grasses are commonly intercropped with legumes to produce high quantity of forage with more balanced nutrition for livestock feeding (Koc *et al.*, 2013). This is so, because legumes increase soil nitrogen through their nitrogen fixation ranging from 32 to 115 kg/ha in symbiosis with rhizobium bacteria (Iannetta *et al.*, 2016). Consequently, sustainable intensification of livestock feed through the aforementioned cropping system maintains continuous cover on the soil. Aside from supplying substantial animal feed, intercropping has many other benefits such as reducing incidence of pests and diseases, suppressing weed population, reducing soil erosion, and supplying additional nitrogen through atmospheric nitrogen fixation (Tamta *et al.*, 2019).

Information about the effect of intercropping on morphological characteristics has been well documented (Idris *et al.*, 2012; Tesfaye, 2019; Gelayenew *et al.*, 2020). A study in Holeta and Debre Zeit Agricultural Research Centers by Gelayenew *et al.* (2020) indicated that mean elephant grass height (cm) was not affected ($P>0.05$) by intercropping with vetch species. This is consistent with the work of Demlew *et al.*, (2019) who observed no significant effect on the height of buffle grass when intercropped with silver leaf desmodium in Gozamin district.

Intercropping affect leaf length and significantly longer leaf length for the intercropped than the sole crop has been reported (Ojo *et al.*, 2013). On top of this, higher leaf: stem ratio has been observed in row intercropping with either Piata palisade grass or Paiaguas palisade grass with Stylosanthes. This is most likely related to the higher nitrogen input because of Stylosanthes (Epifanio *et al.*, 2020). Various findings also showed that grass-legume mixture improve forage yield (Atienza and Rubiales, 2017). Higher DM yield of oat with 25% addition of vetch relative to the sole oat stand has been reported (Negash *et al.*, 2017). In another study conducted at Holetta and Debre Zeit Agricultural Research Centers of the Ethiopian Institute of Agricultural Research (EIAR) by Gelayenew *et al.* (2020), elephant grass intercropped with vetch species produced higher forage yield with improved forage quality. Moreover, intercropping maize with desmodium increased maize stover and grain yield compared to the monocrop and other

legumes (Ndayisaba *et al.*, 2021). This could be due to improved soil fertility through nitrogen fixation by the legumes. Legumes benefit the grass by contributing nitrogen to the soil through atmospheric nitrogen fixation, decay of dead root nodules and mineralization of shed leaves (Meena *et al.*, 2018). In contrast, dry matter accumulation and yields were not influenced due to corn and *Brachiaria* intercropping (Silva *et al.*, 2014). This discrepancy might be due to competition between the two species when grown together. In fact, the intercropping system is blamed for competing among the co-cultivated crops mainly for light, soil, water and nutrients that determines the variations in their productivity (Atis *et al.*, 2012).

Besides, the effect of intercropping on the nutritive value of forages is also indicated in earlier studies (Htet *et al.*, 2016; Berhanu, 2022; Salama *et al.*, 2022). For instance, Htet *et al.* (2016) investigated the effect of intercropping maize (*Zea mays* L.) with soybean (*Glycine max* L.) on green forage yield, and quality and assured that, the crude protein content of intercropped fodder was ($p < 0.05$) higher than sole maize. According to the same author, the fiber contents such as NDF and ADF were lower for intercropped forages as compared to sole maize forage.

2.2.3. Agroecology

The performance and yield of different forage species are markedly different owing to differences in temperature, light intensity, total rainfall, and soil type (Giridhar and Samireddypalle, 2015; Wang *et al.*, 2020; Gong *et al.*, 2023). The effect of altitude on agronomic performance of various forage types has been evaluated by several research scholars (Kebede *et al.*, 2017; Kebede and Bobo, 2023; Adnew *et al.*, 2019).

Adnew *et al.* (2019) observed non-significant effect on some of the morphological characteristics of six *Brachiaria* grass cultivars such as leaf length per plant at low and plant height at mid altitude. Plant height of desho grass was unaffected due to altitudinal differences while leaf length (cm) per plant did so; mid (28.98) and high (21.81) (Asmare *et al.*, 2017). The variation in leaf length may stem from a complex phenomenon controlled by a number of environmental factors such as temperature, precipitation and soil characteristics. Kebede *et al.* (2017) also observed variations in plant height of accessions of Napier grass evaluated at different locations in Ethiopia.

Furthermore, Adnew *et al.* (2019) reported that Mulato II had the highest mean tiller number; low (89.3), mid (86.87), highland (73.09), in all the three altitudes). The large numbers of tillers could imply that grass species allows them to attain maximum growth at an earlier age and recover faster after defoliation. This observation is in discordance with the report of Asmare *et al.* (2017) who found a non-significant effect on tiller number of desho grass.

Dry matter yield of forages varies depending on the altitude where they are cultivated. Adnew *et al.* (2019) obtained high dry matter yield of *Brachiaria* ecotypes at low altitude (5.91 t/ha) compared to high altitude (4.02 t/ha). This corroborates with Kebede *et al.* (2017) who showed DM yield of Napier grass genotypes was significantly affected by changes in environment. According to the same author, the highly significant environmental effect is associated with the large differences among the test environments in altitude, soil types, temperature and differences in both amount and distribution of annual rainfall. However, these findings were inconsistent with the observation of Asmare *et al.*, 2017) who found that DM yield was unaffected by altitudinal difference.

The other variable that changes due to altitude is forage nutritive value. Koutsoukis and Akrida-Demertzi, (2020) studied the effect of altitude on the botanical composition of forage and the variation of its chemical composition in subalpine grassland. According to the same author, the highest mean CP content of the botanical groups and the lowest mean NDF content observed in the plant samples of the highest altitudinal zones as compared to those of the lower zones. In another study by Bayble *et al.* (2007), CP content of 17.46% was reported in the lowland agroecology. Adnew *et al.* (2019) also indicated that, the CP content of *Brachiaria* grass ecotypes was significantly different between the low (12.59%) and high (9.56%) altitudes. Some of the factors contributing variations in CP content of forages in different altitudes could be variations in temperature, precipitation, and soil characteristics.

2.3. Management practices

The optimization of production and nutritive value of grass can be achieved by planting on fertile soils and utilizing forage management tools such as plant spacing and

application of fertilizer (Yiberkew *et al.*, 2020). Tadesse *et al.*, (2021) evaluated the effects of plant spacing and N fertilizer application on dry matter yield and chemical composition of Mulato II grass for the first 150 days after planting. The authors found that DMY, leaf to stem ratio (LSR), CP and fiber contents (NDF and ADF) were significantly ($P < 0.05$) affected by interactions between plant spacing and the level of fertilizer applied. This corroborates with the study reported by Marsetyo and Syukur (2012) who indicated that that increasing level of urea fertilizer application increased Mulato tiller numbers and DM production plus CP and NDF concentrations. Yiberkew *et al.* (2020) evaluated the effects of fertilizer types and plant spacings on plant morphology, biomass yield and chemical composition of Brachiaria hybrid Mulato II grass and concluded that fertilizer types had significant contribution on the brachiaria grass morphology and chemical composition grown in the lowland area of Ethiopia. According to the same authors, the commercial fertilizer (NPS) fertilizer is recommendable for brachiaria hybrid grass production if it is accessible by smallholder farmers; otherwise, the use of manure could be the next option in the study area and in similar environments while, plant spacing of 30 cm x 50 cm, was recommended for better biomass production. Furthermore, Walie *et al.* (2022) showed that application of farmyard manure fertilizer had positive influence ($P < 0.001$) on morphological characteristics, dry matter and crude protein yields (Plant height, LL, LW, LSR, CPY, and DMY) in between Napier and desho grasses in the Aba Gerima watershed. Abusuwar (2019) reported that DMY increments ranged from 53.7% to 118% in the first season and from 146% to 514% in the second for Sudan grass intercropped with clitoria due to combined poultry and cow manure application.

2.4. Importance of Grass-Legume Mixture

In Ethiopia, the available forages for livestock are characterized by nutritional constraints which neither provides sufficient nutrient nor sufficient quantity. One of the most important options to combat the existing challenge is the use of intercropping forages. Intercropping is the agronomic practice of growing two or more crops on the same field at the same time (Asseng *et al.*, 2014).

Intercropping is highly valued elsewhere in the world. Intercropping grasses with legumes enhance forage production with more balanced nutrition for livestock feeding (Koc *et al.*, 2013). The improvement of forage quantity and quality is vital for improved animal performance, a goal of all livestock farmers (Gulwa *et al.*, 2018). Components of a grass-legume mixture may show nutritional complementarity. It has been noted that effects of legumes can persist even if the proportion of legumes in the total biomass is small (Nyfeler *et al.*, 2011).

Greenleaf desmodium may be grown in association with Napier grass (*Pennisetum purpureum*) to improve yield and quality. According to Bayble *et al.* (2007), the protein content of the stand increased from 11% (pure Napier stand) to 15% (mixed sward). Higher herbage yield was also observed in vetch intercropping with elephant grass (Gelayenew *et al.*, 2020). The yield and quality advantage of forage grasses depend on the contribution of legumes in the intercropping regimen.

Legumes are known to perform manifold roles. Forage legume intercropping could play a vital role in response to climate change by reducing soil degradation (Lupwai *et al.*, 2011), improving soil fertility through nitrogen fixation (Muoni *et al.*, 2019), reducing the prevalence of weeds, pests and disease (Lithourgidis *et al.*, 2011). Apart from this, the advantage of intercropping is the more efficient utilization of the available resources and the increased productivity than the corresponding pure stand cropping system (Gou *et al.*, 2016; Hombegowda *et al.*, 2020).

2.5. Nutritive Potentials of Mulato II and *D. intortum* Forages

The quality of forage is determined by factors such as voluntary intake, digestibility, and the efficiency of nutrient utilization (Moore *et al.*, 2020). The nutritive potential of Mulato II has been reported by many research scholars (Nguku *et al.*, 2016; Adnew *et al.*, 2021). Adnew *et al.*, (2021) reported that the grass contains a crude protein content of 12.1% on DM basis. Similarly, Nguku *et al.* (2016) found slightly higher CP content (10.7%) for the same grass cultivar. This CP concentration is well above the minimum requirement (7%) to ensure sufficient supply of nitrogen for rumen microbes and to meet maintenance requirements of animals and support weight gains (Van Soest, 1994) and thus, could be used to supplement low quality feeds. In addition to the CP

concentration, Nguku *et al.* (2016) and Kifuko-Koech *et al.* (2021) noted that Mulato II contained 53.4 and 60.6% NDF concentration, respectively. Obviously, the fiber content of forages might not be similar which attributed to the variations in maturity stage.

The chemical composition of *D. intortum* hay was reported in a previous study (Nurfeta *et al.*, 2009). According to the same authors this forage legume had CP and NDF content of 160 and 518g/kg DM, respectively. In addition, Tolera and Sundstol, (2000) found 533g/kg DM of NDF content for the same forage legume and noted its potential in supplementing protein to ruminants which received diets with low quality or deficient in CP.

2.6. Nutrient Requirement of Sheep

Feed is the most limiting factor in many parts of the tropics since it is the main driver of livestock production (Makkar, 2016; Makkar, 2018). Sheep and goat production in Ethiopia suffers from feed shortages with an estimated 40% deficit in the national feed balance. As a result, energy and protein deficiencies are the principal factors limiting the performance of small ruminants (Yami, 2008).

2.6.1. Energy

The right nutrition provided at the right stage is vital to the profitability of small ruminants. Poor quality pastures and roughage or inadequate amounts of feed are the major predisposing factors for small ruminants to be in a state of energy deficit (Spencer, 2019). Particularly, meeting energy requirements without over or underfeeding animals is one of the producers' most tedious works. According to NRC, (1985), the sheep sector has faced energy deficiency or inefficiency and is likely the most widely occurring nutritional deficiency. Within species, energy density of gain is known to be affected by genotype, sex, body weight, level of intake, rate of gain, and concentration of energy in feedstuffs. The energy values of proximate constituents of feedstuffs are 4.2, 9.2, and 5.6 Kcal/g for carbohydrates, fat, and protein, respectively.

The energy requirement for 1g average daily gain (ADG) has been estimated to be 24.3 kJ ME (Salah *et al.*, 2013). According to McDonald *et al.* (2010), daily energy

requirements for a 20 kg live weight lambs gaining 0, 50,100, and 150 g/day are presented in the following Table (Table 2.1).

Table 2.1. The daily energy requirement of sheep (MJ/ day)

Animal	Live weight gain (g/day)				DMI (Kg/day)
	0	50	100	150	
Male	3.9	4.8	5.8	6.4	0.46
Castrated	3.4	4.5	5.7	6.2	0.46
Female	3.4	4.5	5.8	6.5	0.46

2.6.2. Protein

The other critical nutrient for young growing animals and most expensive component of feed for small ruminants is protein (Ružić-Muslić *et al.*, 2014). Microbial and rumen undegradable protein are the two main protein fractions that reach the small intestine of ruminants. Microbial protein is produced by the action of the rumen flora, which breaks down the dietary protein to peptides, amino acids and ammonia (McDonland *et al.*, 2010). Good quality forage and pasture generally provide sufficient protein for mature, non-growing, non-lactating sheep. The protein requirement of sheep is influenced by several factors such as stage of production and the presence of certain diseases. The minimum maintenance requirement of dietary crude protein for most sheep is 7% (Pugh, 2020). As it is often claimed, low quality feeds are the major impediments to productivity of livestock. Supplementing low quality feeds with protein rich feed resources is crucial to ameliorate the profitability of the livestock sector. According to Mengesha *et al.* (2017), the protein concentration of the diet consumed should be above 10% to maintain optimum productivity in small ruminants. In this view, including legume forages into the feeding system has been suggested as a viable method to improve the quality of the basal diet and meet animal requirements (Bezabih *et al.*, 2016).

2.7. Relationship between feeds and blood profiles in animals

There is a well-established relationship between nutrition and immunity (Bertoni *et al.*, 2016). Animals must meet their nutritional requirements not only for maintenance, growth, and reproduction but also to support an effective immune response. Nutrition,

particularly the quality and composition of animal feed, plays a critical role in influencing blood parameters, which serve as indicators of an animal's health, metabolic status, and feed efficiency. Blood cell parameters, assessed through complete blood count (CBC) analysis, provide valuable insights into overall health and metabolic condition (Riedesel *et al.*, 2015). For instance, normal hematological values suggest adequate nutrient intake and a stronger immune status in animals.

Moreover, blood glucose concentrations are closely correlated with dry matter intake and metabolizable energy consumption. Low dry matter intake leads to reduced blood glucose levels, while adequate energy intake is associated with higher blood glucose concentrations (Przemysław *et al.*, 2015). According to Saro *et al.* (2020), propionate is the primary substrate for gluconeogenesis in ruminants. A decline in dry matter and carbohydrate intake can reduce propionate supply, thereby limiting glucose synthesis. Serum proteins, which are primarily synthesized in the liver, reflect the functional capacity of hepatocytes. A decrease in serum protein levels such as total protein (TP), albumin, and globulin and may indicate hepatic dysfunction, malnutrition, or ongoing inflammation, often associated with recurrent infections and immune deficiencies (Tóthová *et al.*, 2016).

2.8. Enteric Methane Emission

Nowadays, methane concentration is increasing all over the world. It is one of the biggest environmental threats produced from the enteric fermentation by livestock ruminants (Broucek *et al.*, 2014). Within ruminants, cattle are the highest daily emitters on a per animal basis, followed by sheep, with goats and buffalos having similar emissions. There are several factors which affect enteric methane emission of animals such as chemical composition of the diet, feeding level, and inclusion of certain feed additives. However, it is largely influenced by nutritive value of feeds (Quintero-Anzueta *et al.*, 2021). Enteric methane emission and fiber content of feeds are positively correlated while its relationship with energy dense feedstuffs with high lipid content is negative (Benaouda *et al.*, 2019). Consequently, high quality feeds coupled with high dry matter intake resulted in lower enteric methane emission and lower energy loss (Gaviria-

Uribe *et al.*, 2020). On top of this, Van Gastelen *et al.* (2019) reported a decreased enteric methane yield in sheep as forage digestibility increased.

Obviously, enteric methane emission resulted in loss of significant amount of feed energy which otherwise used for production (van Wyngaard *et al.*, 2018). Donadia *et al.* (2023) noted that balancing the higher demand for animal products while decreasing greenhouse gas emissions remains one of the prominent challenges of the livestock sector.

There is a considerable interest by several scholars to deal with the abatement of methane emission (Black *et al.*, 2021; Loza *et al.*, 2021). Decreasing enteric methane emissions from cattle would enhance environmental safety and improve productivity and profitability (Min *et al.*, 2022). According to Eugène *et al.* (2021) feeding ruminants with high quality forages can reduce the contribution of livestock and agriculture to GHG emission. Forage quality is influenced by stage of maturity and species mixture. A study showed that intercropping tropical grasses with legumes play utmost role to reduce greenhouse gas emissions in livestock production systems (Furtado *et al.*, 2023). According to the same authors, inclusion of pigeon pea (*Cajanus cajan* L. Millsp.) intercropped with *Urochloa* species met the nutritional requirements of the steers which led to improve performance as well as decreasing the intensity of enteric methane emissions.

CHAPTER 3: GENERAL MATERIALS AND METHODS

This dissertation comprised four manuscripts, each of them are presented as chapters (**Chapter 4- Chapter 7**). The fourth chapter details about the production and utilization practices of Mulato II and *D.intortum* forages. The fifth chapter discusses the morphological, yield, and nutritive value of Mulato II and *D. intortum* as influenced by planting pattern, agroecologies, and harvesting ages. The sixth chapter elucidates the replacement of concentrates with Mulato II and *D. intortum* mixed forage on intake, digestibility, and average daily gain of yearling rams. Finally, the seventh chapter presents the substitution effect of concentrate with Mulato II and *D. intortum* mixed forages on the blood profiles and enteric methane emission of Farta rams. The materials and methods shown in this section are general and the detailed methodologies are available within each of the manuscripts (Chapters) imbedded herein.

3.1. Study Areas

The survey work on forage production and utilization practices (**Chapter 4**) was conducted in Kalu and Dawa Chefa districts of Eastern Amhara Region, Ethiopia (Appendix A, Figure 1). Kalu district is situated at 11°31'05'' North latitude and 39°36'34'' East longitude with an altitude ranging from 1400 to 1850 m.a.s.l. The mean annual minimum and maximum temperatures are 12.5 and 22.5 °C, respectively and the mean annual rainfall ranges from 700 to 900 mm in a bimodal pattern. Dawa Chefa district is located at 10° 43' North latitude and 39° 52' East longitude. Its altitude ranges from 1500 to 2300 m.a.s.l. The annual rainfall of the district ranges from 660 to 1100 mm and the mean annual temperature ranges from 19.7 to 24.1 °C.

The agronomic study of the forages (**Chapter 5**) was done in Ambomesik (North Mecha district) and Gendewuha (Metema district), Northwest Ethiopia (Appendix A, Figure 2). Metema is located between 12°19'19'' and 13°27'08'' North latitude and 35°51'20'' and 36° 49' 44'' East longitude. Its altitude ranges from 550 to 1068 m.a.s.l. The mean annual temperature ranges from 22 to 28 °C. The mean annual rainfall of the area ranges from 850 to 1100 mm and has uni-modal pattern. On the other hand, North

Mecha is situated at 9°23' to 9°26' North latitude and 41°59' to 42°02' East longitude. The altitudinal range of the area spills from 1807 to 2300 m.a.s.l. The mean annual minimum and maximum temperatures are 10 °C and 27 °C, respectively. The area receives mean annual rainfall which ranges from 1000 to 2000 mm.

The chemical analysis of the forages (**Chapter 5**) was carried out at Holeta Agricultural Research Centre Animal Nutrition Laboratory. The feeding trial experiments (**Chapters 6 and 7**) were done at sheep and goats research farm of Zenzelma Campus, Bahir Dar University (Appendix A, Figure 3). The farm is situated at 11°37' North latitude and 37°28' East longitude with an altitude of 1911 m.a.s.l. The annual average temperature of the area was 29 °C and had an average annual rainfall range (1428 to 1521 mm).

3.2. Sampling Techniques and Procedures

For the survey work (**Chapter 4**), study sites and households were selected purposively based on the practice of push-pull technology and animal production potential. In this technology Mulato II and *D. intortum* forages are produced which have been used as animal feeds. Three rural *kebeles* (smallest administrative unit) from each of the districts and 30 households from each *kebele* were purposively selected, making a total of 180 respondents for survey data collection.

For the agronomic experiment (**Chapter 5**), the land was ploughed and properly prepared in May and harrowed to make fine bed in June 2022 in each of the two locations, lowland (Gendewuha) and midland (Ambomesik) agroecologies. The fine prepared bed was made to contain three blocks and within each block, there were 6 plots, a total of 18 plots per location. The planting material for Mulato II was collected from Andassa Livestock Research Center, while that of *D. intortum* was obtained from Chagni ranch. The experiment was laid out in factorial arrangement using a randomized complete block design (RCBD) with three replications. The treatments were combined with three factors (planting pattern: sole Mulato II, Sol *D. intortum*, and Mulato II intercropped with *D. intortum*, agroecologies; lowland and midland, and harvesting ages: 90 and 120 days) into 2*2*2 factorial arrangement of treatments. Planting was done using vegetative root

splits of Mulato II and root cuttings of *D. intortum* forages during the main rainy season. The intra and inter row spacing were 50 and 30 cm, respectively for Mulato II grass. The spacing between plot and block was 0.5 and 1 m, respectively. *Desmodium intortum* was planted between rows of Mulato II while intercropping.

For the animal evaluation experiments (**Chapter 6** and **7**), twenty-five yearling castrated Farta rams with an average initial body weight of 18 ± 1.36 kg (mean $\pm$ SD) were used. Before the commencement of the experiment, sheep were placed on individual pen for 15 days of preliminary period to enable experimental animals get accustomed to the new environment and acclimatize the test feeds.

After the acclimatization period, animals were weighed after overnight fasting for two consecutive days and the average body weight was taken to categorize them into blocks. The sheep within each block were then assigned randomly to one of the five treatment diets using Randomized Complete Block Design (RCBD). Five dietary treatments were used for this sheep evaluation experiment. The concentrate was replaced progressively by Mulato II and *D. intortum* mixed forages at a proportion of 0, 20, 40, 60 and 80% where supplements were set at 400 g/head/day (Asmare *et al.*, 2010) for each of the treatments made to be nearly iso-caloric and iso-nitrogenous. The concentrate contained noug seed cake, wheat bran, and ground maize grain. The sheep were offered with the basal diet (natural pasture hay) *ad libitum* with the amount fed adjusted weekly to allow a 20% refusal and had free excess to clean water.

3.3. Data Collection

3.3.1. Survey data

A semi-structured questionnaire was developed and administered by experienced and trained enumerators to collect the data (**Chapter 4**). Four elderly people and one *kebele* leader, a total of five people per *kebele* leaders, were recruited to undergo the focus group discussion, whereas three animal science experts and the head of the district livestock resource promotion agency per district, were selected as key informant interview. Besides, secondary data for data such as description of study areas were

obtained from different sources such as agricultural and rural development offices, published articles, books, and websites. The data collected in this survey study were the production and extent of use of *Brachiaria* and *D. intortum* forages as livestock feed and the constraints associated with them.

3.3.2. Agronomic data

The data on morphological and yield parameters were recorded at each harvesting period in each of the study locations (**Chapter 5**). Plant height per plant (PHPP) and leaf length per plant (LLPP) were measured with measuring tape and the number of tillers (NTPP), number of leaves (NLPP), and numbers of roots per plant (NRPP) for Mulato II were computed as mean of counts. The morphological characteristics (PHPP: plant height per plant; NBPP: number of branches per plant and NRN: number of root nodule) for *D. intortum* were also treated similarly. Ten plants were randomly selected in the middle of each plot to record the morphological characteristics at each harvesting ages in both locations.

3.3.3. Animal evaluation experiments

The feeding trial lasted 90 days excluding the 15 days of acclimatization period. The feed offered and refusals were recorded daily for each lamb and the feed intake was determined by subtracting the hay refusal from the daily feed offer. Initial body weight was taken at the start of the actual feeding experiment. Body weight was measured every 15 days after overnight fasting in the morning before the feed offer. The final body weight measurement was taken at the end of the feeding experiment. The daily body weight gain was computed as the difference between final and initial body weight divided by number of feeding days. The feed conversion efficiency (FCE) was calculated by dividing the average daily weight gain to average daily feed intake in grams.

At the end of the feeding experiment, the digestibility experiment was done using all sheep which were allowed to adapt harnessing of fecal collection bags for four days. During the actual data collection period, the fecal sample was collected separately using fecal collection bag fitted to each experimental animal for 7 consecutive days. Feed refusals and faeces were collected and weighed every day in the morning and fecal

sample was kept frozen at -10 °C in refrigerator. At the end of the digestibility trial, a composite fecal sample of 20% was taken and pooled over the collection period for each animal. The collected fecal sample was partially dried at 65 °C for 72 hours. The oven dried sub-samples and the feed offered were then ground to pass through a 1 mm sieve size and taken to Holeta Agricultural Research Center Animal Nutrition Laboratory for chemical analysis. The digestibility of each nutrient was then calculated using the equation as follows:

$$\text{Apparent digestibility (\%)} = \frac{\text{Nutrient in feed} - \text{Nutrient in faeces}}{\text{Nutrient in feed}} * 100$$

Like for growth performance, data on the blood profiles and enteric methane emission were taken from all sheep. Automated hematological analyzer (BC-5800 Automated hematological analyzer, Mindray, China) was used for hematological tests (RBC, WBC, PLAT, Hgb, HCT, MCV, MCH, and MCHC). While, blood biochemical parameters (blood glucose, Total protein, Albumin, Urea nitrogen, and Total cholesterol) were analysed by using automated blood biochemical analyser. Further, portable hand-held laser methane gas detector (LMD; Tokyo Gas Engineering Co. Ltd. Tokyo, Japan) was used to measure the enteric methane emission of the experimental sheep.

3.4. Chemical Analysis

Samples of forages collected during agronomic, feeding trial (samples of feed offered and refusal), and faeces were dried at 65 °C for 48 hours. The dried samples were then ground using Willey mill to pass through 1 mm sieve size for chemical analysis. DM and ash contents of samples were determined following the procedure of AOAC (2005). The dry matter content of feed samples was determined by drying the sample in forced draft oven at 105 °C overnight. Ash was determined by complete burning or igniting feed samples in a muffle furnace at 550 °C for three hours. Organic matter (OM) percentage was calculated as 100 minus ash content. Kjeldhal procedure (AOAC, 2005) was used to determine total nitrogen (N) and crude protein (CP) was then calculated as N*6.25. Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were analyzed using Van Soest *et al.* (1991).

3.5. Data Analysis

Descriptive statistics, mean comparisons, and percentage values and tabular presentations were used to analyze the survey data employing SPSS v.26 computer software. Index values were calculated by employing the following formula (Kosgey, 2004): $\text{Index} = \frac{\text{sum of } (N \times 1^{\text{st}} \text{ order} + (N-1) \times 2^{\text{nd}} \text{ order} + (N-2) \times 3^{\text{rd}} \text{ order} + \dots + (N-n) \times n^{\text{th}} \text{ order})}{\text{sum of } (N \times 1^{\text{st}} \text{ order} + (N-1) \times 2^{\text{nd}} \text{ order} + (N-2) \times 3^{\text{rd}} \text{ order} + \dots + (N-n) \times n^{\text{th}})}$ for all variables. Where; N= number of variables considered for ranking; and n= order

All data collected from the agronomic study (morphological characteristics and laboratory analysis of forage samples) and animal evaluation experiment were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of Statistical Analysis System (SAS) software, version 9.4. Least significance difference (LSD) test was used to separate the treatment mean at 5% significant level for the agronomic and animal evaluation experiment.

The model statement for the agronomic study (**Chapter 5**) was: $Y_{ijk} = \mu + T_i + A_j + H_k + T_i * A_j + T_i * H_k + A_j * H_k + T_i * A_j * H_k + \epsilon_{ijk}$

Where; Y_{ijk} = dependent variables (data on morphology, forage yield and chemical composition)

μ = Overall mean

T_i = Treatment effect (planting pattern effect: sole Mulato II, sole *D. intortum*, and Mulato II intercropped with *D. intortum*)

A_j =effect of agroecologies (lowland and midland agroecologies)

H_k = effect of harvesting ages (90 and 120 days)

$T_i * A_j$ = interaction effect of planting pattern and agroecologies

$T_i * H_k$ =the interaction effect of harvesting ages and planting pattern

$A_j * H_k$ = interaction effect of agroecologies and harvesting ages

$T_i * A_j * H_k$ = three-way interaction (planting pattern, agroecologies, and harvesting times)

ϵ_{ijk} = residual error

On the other hand, the model for animal evaluation experiments (**Chapter 6 and 7**) was:

$$Y_{ij} = \mu + T_i + B_j + \epsilon_{ijk}$$

Where Y_{ijk} = response variable

μ = overall mean

T_i = treatment effect

B_j = block effect

ϵ_{ijk} = residual error

OriginPro software was used to plot the graphs.

CHAPTER 4: MULATO II AND GREENLEAF DESMODIUM (*Desmodium intortum*) PRODUCTION AND UTILIZATION PRACTICES BY LIVESTOCK FARMERS IN ETHIOPIA

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Brachiaria hybrid cv Mulato II and Greenleaf desmodium (*Desmodium intortum*) production and utilization practices by livestock farmers in Ethiopia

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Abstract

The study was conducted to assess Mulato II and *D. intortum* production and utilization practices in selected areas of Eastern Amhara Regional State, Ethiopia. For this study, two districts namely, Kalu and Dawa Chefa with a total of 180 respondents, 90 respondents from each district, were purposively selected. Data collected were production, utilization practices, and the constraints associated with them. The collected data through questionnaire were analyzed by descriptive statistics using SPSS version 26. The average land holding per household was 1.5 ± 0.59 ha. Feed shortage was ranked first in both study areas. Mulato II and *D. intortum* forage species were very important livestock feeds which were mainly produced in association with push-pull technology PPT (91.1 and 85.6%) during the main rainy season (100 and 98.9%) in Kalu and Dawa Chefa districts, respectively. The result revealed that the majority of respondents (58.9 and 74.4%) experienced in the production of Mulato II and *D. intortum* in Kalu and Dawa Chefa districts, respectively. Most of the farmers (63.3 and 74.4%) were used cut

and carry system to feed their livestock in Kalu and Dawa Chefa districts, respectively. The main purposes of Mulato II and *D. intortum* were crop pest control such as stem borer and livestock feed in both study areas. But, land scarcity and shortage of planting materials were the major impediments. Lack of awareness was the other reported constraint by the majority of respondents (91.1 and 94.4%) in Kalu and Dawa Chefa districts, respectively. Thus, farmers could be supported through training and providing planting materials.

Keywords: Mulato II, *Desmodium intortum*, Forage, Push-pull technology, Cut and carry

4.1. Introduction

Ethiopia has the largest livestock population in Africa, comprising 70 million cattle, 42.9 million sheep, 52.5 million goats, 10.8 million donkeys, and 8.1 million camels (CSA, 2021). Livestock play a vital role in the people's livelihoods by providing draft power, income, employment, food, and insurance (FAO, 2018). Despite the huge livestock numbers, manifold roles and favorable environmental conditions of the country, their productivity is far below their potential and unable to meet the demands of the rapidly growing human population in the foreseeable future (Shapiro *et al.*, 2015). Although there several other factors, feed shortage in terms of quality and quantity is the major bottleneck for productivity (Assefa *et al.*, 2013).

Though natural pasture and crop residues are the major feed resources, they are poor in nutritive value and could not support beyond the maintenance requirements of the animals (Shapiro *et al.*, 2017; Avadhanam *et al.*, 2020). For animals to perform to their full potential, they need supplemental feeds to meet their nutritional requirements, increase feed intake and provide animals with additional nutrients (Lengarite *et al.*, 2012). Despite over five decades of forage research and development in the country, improved forages have had a negligible impact on livestock feed (CSA, 2021). The primary reasons for this problem include farmers' limited production and knowledge, a shortage of planting materials, and insufficient land for fodder cultivation (Workye *et al.*, 2018; Fentahun *et al.*, 2020).

Nowadays, both the availability and price of concentrate feeds are also becoming more challenging for the majority of the smallholder livestock producers in the country. On top of this, the production of cereals (maize and sorghum) has been also constrained with pests such as striga and stemborers (Murage *et al.*, 2015; Benjamin *et al.*, 2024). As a solution, Mulato II and *D. intortum* have been used in push pull technology; could be considered as an integrated pest management of cereal production (Hassen *et al.*, 2019; Khan *et al.*, 2019). This integrated pest management technique using Brachiaria hybrid grasses particularly cv Mulato II and *D. intortum* could be called push-pull technology (PPT). In this PPT, *D. intortum* is a repellent intercrop while Mulato II is an attractive trap plant. As an additional advantage of the PPT, these improved forages (Mulato II and *D. intortum*) are useful sources of energy and protein nutrients, respectively and considered as a promising approach in getting quality and quantity of forage in the production system (Khan *et al.*, 2011). The use of a grass-legume mixture would serve as a good alternative to reduce production costs, increase both quantity and quality of the forage and soil rehabilitation (Dhakal and Islam, 2018), make the environment more sustainable and pave the way for climate resilient options (Gulwa *et al.*, 2017). The PPT could also support the integration of crop-livestock production system to be productive, resilient and sustainable, since the majority of farmers adopt it (Hassen *et al.*, 2019).

Most of the PPT studies documented the roles of Mulato II and *D. intortum* from pests' management point of view for maize and sorghum cereal production (Dejen, 2014; Hassen *et al.*, 2019) with limited information about Mulato II mixed with forage legumes as livestock feed (Adnew *et al.*, 2018) and *D.intortum*. Hence, there is limited information about how those forages are produced and utilized by farmers in the production system. Supporting farmers through the identification and promotion of forage species enriched with manifold merits such as high nutritive value, wide adaptability to drought and low soil fertility is crucial to tackle feed shortage (Ghimire *et al.*, 2015; Mundia, 2021). Mulato II and *D. intortum* are among the potential forages that could help to improve livestock productivity. Exploitation of PPT through the improved forages (Mulato II and *D. intortum*) could contribute in reducing the current Ethiopia's livestock feed gap both in dry matter and critical nutrients such as protein and energy

(FAO, 2018). The PPT could also benefit the improved forage production in the country which otherwise be limited for sole forage cultivation because of land shortage.

Looking for such information on Mulato II and *D. intortum* is of paramount importance in setting future development strategies, research plans and any intervention options for sustainable livestock production while maintaining the natural environment. Thus, this study was conducted to assess the production and utilization practices of Mulato II and *D. intortum* as livestock feed in selected areas of Eastern Amhara Regional State, Ethiopia.

4.2. Materials and Methods

4.2.1. Description of study areas

The survey work on Mulato II and *D. intortum* production and utilization practices were conducted in Kalu and Dawa Chefa districts where the practice of PPT are common with which these forage species produced and animal production potential as a basis of selection.

Kalu district is located in South Wollo administrative zone, Amhara Regional State, Northeast of Addis Ababa, Ethiopia. Geographically, it is situated at 11°31'05'' North latitude and 39°36'34'' East longitude. Kombolcha, the capital of the district, is located at 380 km from Addis Ababa. The altitude of the district ranges from 1400 to 1850 m.a.s.l. The mean annual minimum and maximum temperatures are 12.5 and 22.5 °C, respectively. It receives a mean annual rainfall of 700-900 mm in a bimodal pattern. The long rainy season (*Kirmet*) occurs from June to August, while the short rainy season (*Belg*) lasts from January to March.

Dawa Chefa district is located in the Oromia administrative zone of Amhara Regional State. It is situated at 10° 43' N latitude and 39° 52' E longitude. The altitude of the area ranges from 1500 to 2300 m.a.s.l. The district falls within the dry Kolla agroclimatic zone. The rainfall distribution of the area is highly seasonal and has temporal variations. The annual rainfall of the district ranges from 660-1100 mm. The mean annual temperature ranges from 19.7 to 24.1 °C.

4.2.2. Sample size and sampling technique

Each district was purposively selected for the study based on the practice of push-pull technology and animal production potential. Three rural *kebeles* (smallest administrative unit) from each district and 30 farmers from each *kebele* were purposively selected depending on push pull technology practice; as Mulato II and *D. intortum* production involved in the system (Appendix D, Figure 4.1). A total of 180 respondents, 30 from each *kebele* were purposively selected in both study areas.

4.2.3. Data collection techniques

A semi-structured questionnaire (combination of open-ended and close-ended questions) was developed and administered to collect the data. Open-ended questions allowed respondents to express their thoughts and opinions without restrictions, while close-ended questions present choices from which respondents can select their answers. Focus group discussions and key informants' interview were also used to complement the questionnaire survey (Williamson, 2017). For focus group discussion, elderly people and *kebele* leaders were recruited, whereas animal science experts and the head of the district livestock resource promotion agency were selected as key informant interview.

In addition, secondary data for independent variables such as study area description were obtained from agricultural and rural development offices, published articles, books, and websites. The data collected were socioeconomic characteristics, Mulato II and *D. intortum* production, utilization and management practices, the push-pull technology as improved forage source, and associated challenges. The dependent variables tested were the production and extent of use of Mulato II and *D. intortum* as livestock feed and the constraints associated with them. The preliminary and actual household surveys were conducted during 2022-2023.

4.2.4. Statistical analysis

Prior to conducting the data analysis, the household questionnaires were organized, sorted, and coded in MS excel sheet. Following coding, the collected data on survey study was analyzed to interpret the result accurately. Descriptive statistics, mean comparisons, and percentage values and tabular presentations were used to analyze

survey data employing SPSS version 26 computer software. For two means comparison, T test was used.

In addition, index values were used to rank some of the variables under study. Index values were calculated by employing the following formula (Kosgey, 2004):
Index= sum of $(N \times 1^{\text{st}} \text{ order} + (N-1) \times 2^{\text{nd}} \text{ order} + (N-2) \times 3^{\text{rd}} \text{ order} + (N-n) \times n^{\text{th}} \text{ order})$ for individual variables divided by the sum of $(N \times 1^{\text{st}} \text{ order} + (N-1) \times 2^{\text{nd}} \text{ order} + (N-2) \times 3^{\text{rd}} \text{ order} + (N-n) \times n^{\text{th}})$ for all variables; where N= number of variables considered for ranking; and n= order

4.3. Results

4.3.1. Socioeconomic characteristics of respondents

Table 4.1 shows the socioeconomic characteristics of respondents. The majority of the household heads, 72.2% in Kalu and 53.3% in Dawa Chefa were illiterate. Only 2.2 and 5.6% of the respondents completed secondary school (grade 9-12) in Kalu and Dawa Chefa districts, respectively. Family size varied significantly ($p < 0.05$) between the study districts. On average, the family size of households in Kalu and Dawa Chefa districts were 5.93 and 6.49, respectively. Furthermore, mixed farming (92.2 and 97.8%) was predominantly practiced by interviewed farmers in Kalu and Dawa Chefa districts, respectively. The land holding per household varied significantly ($p < 0.05$) between the two study areas. On average, the average land holdings of a household in Kalu and Dawa Chefa districts were 1.3 and 1.7 ha, respectively.

Table 4.1. Socioeconomic characteristics of the respondents

Description	Kalu N (%)	Dawa Chefa N (%)	<i>P</i> value
Sex			
Male	82 (91.1)	79 (87.8)	
Female	8 (8.9)	11 (12.2)	
Age			
18-30	7 (7.8)	9 (10.0)	
31-40	16 (17.8)	26 (28.9)	
41-50	45 (50)	38 (42.2)	
51-60	13 (14.4)	10 (11.1)	
60+	9 (10)	7 (7.8)	
Educational level			
Illiterate	65 (72.2)	48 (53.3)	
Grade 1-4	18 (20)	24 (26.7)	
Grade 5-8	5 (5.6)	13 (14.4)	
Grade 9-12	2 (2.2)	5 (5.6)	
Major occupation			
Livestock farming only	4 (4.4)	2 (2.2)	
Mixed farming	83 (92.2)	88 (97.8)	
Mixed farming and trading	3 (3.3)	-	
	Mean±SE	Mean±SE	<i>P</i> value
Family size			
Total family size	5.93±0.16	6.49±0.14	0.011
Land holding (ha)			
Cultivated land	1.04±0.04	1.4±0.04	0.000
Grazing land	0.11±0.02	0.15±0.02	0.174
Fallow land	0.04±0.01	0.06±0.01	0.150
Cultivated fodder land	0.07±0.01	0.1±0.01	0.179
Total land holding	1.3±0.06	1.7±0.06	0.000
Overall	1.5±0.59		

N=number of respondents; SE= standard error

4.3.2. Feed shortage and mitigation strategies of respondents

Feed shortage mitigation strategies of the respondents in study districts are shown in Table 4.2. In this study, all of the interviewed farmers mentioned that they experienced feed shortage for their livestock in both study areas. The majority of the respondents (78.9 and 94.4%) reported that they faced seasonal feed shortage particularly during the dry season in Kalu and Dawa Chefa districts, respectively.

Purchasing crop residues (Kalu: 47.8 and Dawa chefa: 63.3%) followed by stock reduction (Kalu: 27.8 and Dawa chefa: 15.6%) were the major feed shortage coping mechanism by the interviewed farmers. The practice of purchasing concentrate feeds as a means of mitigating feed shortage in both study areas was the least preferred option relative to the other coping strategies.

Table 4.2. Feed shortage and coping mechanism of respondents

Description	Kalu N (%)	Dawa Chefa N (%)	Overall N (%)
Feed shortage			
Yes	90 (100)	90 (100)	180 (100)
Seasonality of feed shortage			
Dry season (Mid November-May)	71 (78.9)	85 (94.4)	156 (86.7)
Wet season (June- October)	3 (3.3)	1 (1.1)	4 (2.2)
Both seasons	16 (17.8)	4 (4.4)	20 (11.1)
Mitigating strategies			
Purchasing concentrate feeds	3 (3.3)	6 (6.7)	9 (5)
Rent grazing land	6 (6.7)	8 (8.9)	14 (7.8)
Purchasing crop residues	43 (47.8)	57 (63.3)	100 (55.6)
Stock reduction	25 (27.8)	14 (15.6)	39 (21.7)
Minimizing the amount of daily feed supply	13 (14.4)	5 (5.6)	18 (10)

N= Number of respondents

4.3.3. Available improved forages and their utilization practices

The available improved forage types in both study areas are shown in Figure 4.2. The result showed that all of the respondents owned Mulato II and *D. intortum* since they were engaged in PPT and purposively selected. On top of this, other types of improved forages were cultivated in both districts. In decreasing order of their availability (decreasing order of respondent's percentage), Sesbania (*Sesbania sesban*), Elephant grass (*Pennisetum purpureum*), Oat (*Avena sativa*), Vetch (*Vicia dasycarpa*), Tree lucerne (*Chamaecytisus palmensis*), Lablab (*Lablab purpureus*), Alfalfa (*Medicago sativa*), and Cowpea (*Vigna unguiculata*) were the major improved forage types in Kalu district. On the other hand, Sesbania (*Sesbania sesban*), Elephant grass (*Pennisetum purpureum*), Vetch (*Vicia dasycarpa*), Oat (*Avena sativa*), Lablab (*Lablab purpureus*), Cowpea (*Vigna unguiculata*), Tree Lucerne (*Chamaecytisus palmensis*), and Alfalfa

(*Medicago sativa*) were the available improved forage types in Dawa Chefa district. This study revealed that *Sesbania sesban* (84.4 and 75.3%) and *Pennisetum purpureum* (70 and 51.1%) forages were cultivated by the majority of respondents in Kalu and Dawa Chefa districts, respectively.

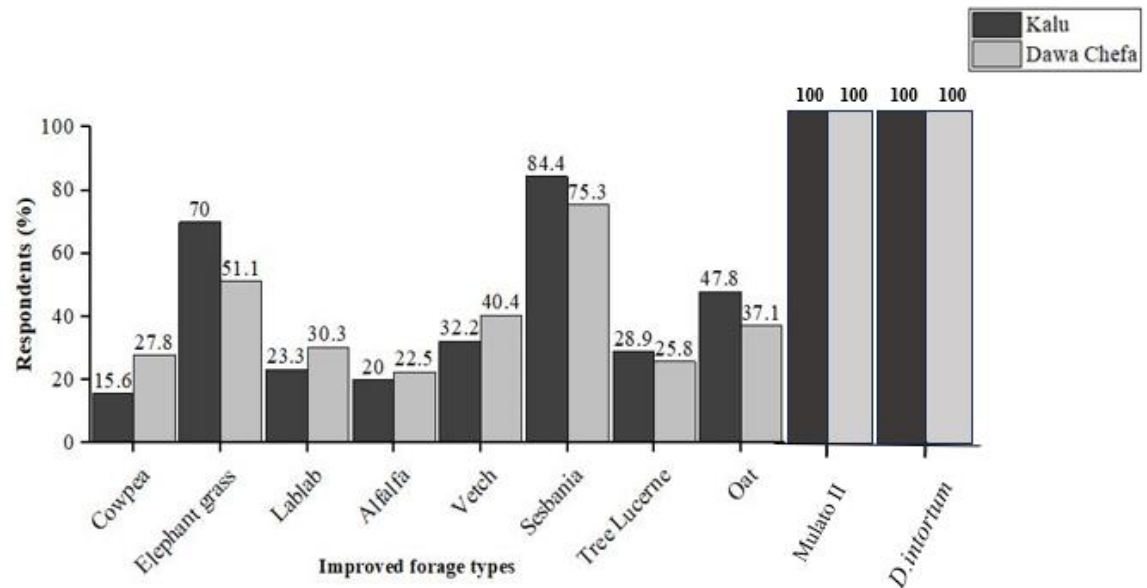


Figure 4.1. Available improved forage types in the study districts

Improved forage utilization practices are presented as shown in Figure 4.3. The majority of respondents (Kalu: 63.3 and Dawa chefa: 74.4%) used cut and carry system followed by direct grazing (Kalu: 53.3 and Dawa chefa: 55.6%) to feed their livestock.

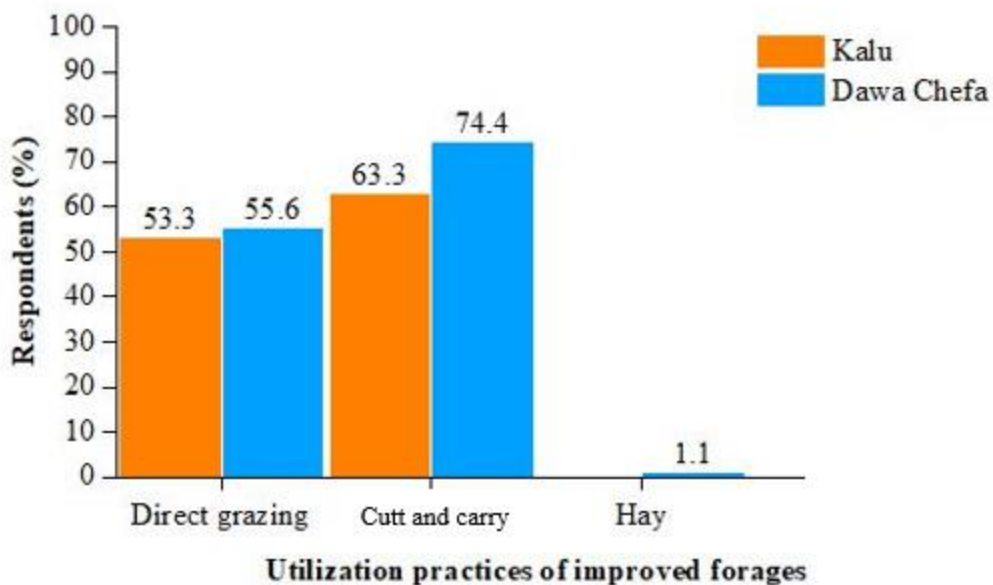


Figure 4.2. Utilization of improved forages in the study areas

4.3.4. Challenges of improved forage production

The major constraints that impede the production of improved forage in the study areas are identified as shown in Table 4.3. Respondents ranked land shortage (index= 0.28), planting material scarcity (index= 0.24) and financial problem (index= 0.16) as the 1st, 2nd and 3rd major constraints for improved forage production in both study areas. In addition, poor extension service was another challenge that was ranked (5th) in both study areas.

Table 4.3. Major challenges of improved forage production

Constraints	Kalu		Dawa Chefa	
	Index	Rank	Index	Rank
Land scarcity	0.28	1	0.28	1
Shortage of planting material	0.24	2	0.24	2
Financial problem	0.16	3	0.16	3
Drought	0.075	6	0.14	4
Free grazing	0.14	4	0.08	6
Poor extension service	0.102	5	0.10	5

4.3.5. Mulato II and *D. intortum* production in the study areas

Production strategies of Mulato II and *D. intortum* by the respondents are shown in Figure 4.4. Accordingly, respondents indicated that Mulato II and *D. intortum* were cultivated in the border of push-pull technology only (PPT) (91.1 and 85.6%), backyard and PPT (7.8 and 11.1%), and soil bunds, roadside and stock enclosure areas and PPT (5.6 and 8.9%) in Kalu and Dawa Chefa districts, respectively.

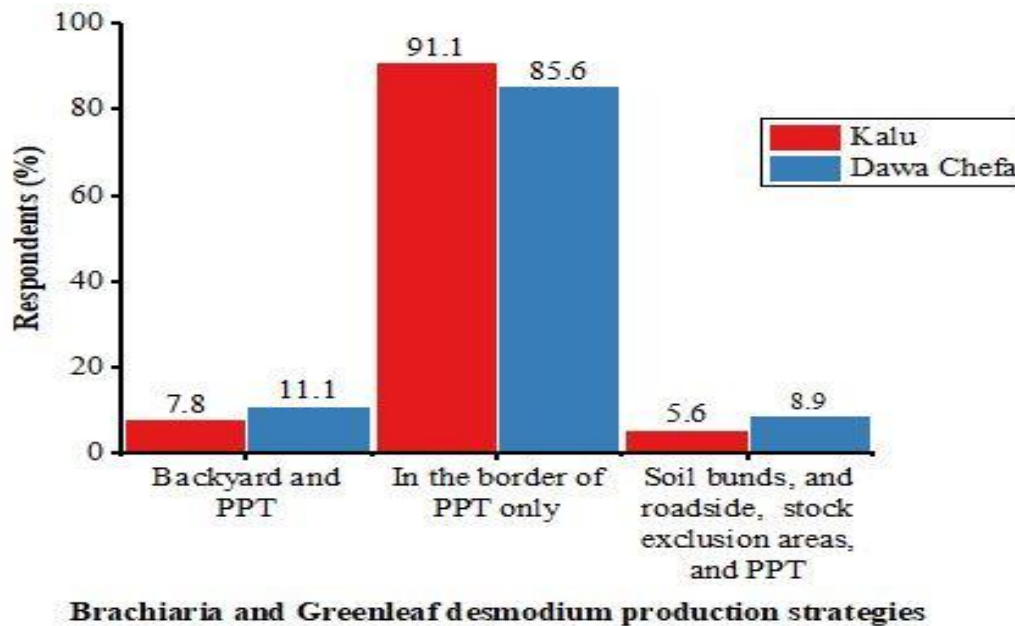


Figure 4.3. Mulato II and *D. intortum* production strategies

Experience in Mulato II and *D. intortum* production, planting materials, sources of planting materials, planting and harvesting seasons are presented in Table 4.4. The majority of respondents (58.9 and 74.4%) were experienced in the production of Mulato II and *D. intortum* in Kalu and Dawa Chefa districts, respectively.

The planting materials used for Mulato II and *D. intortum* were seed (Kalu: 82.2 and Dawa chefa: 52.2%) followed by both seed and seedlings or tillers (Kalu: 17.8 and Dawa chefa: 47.8%). The use of seed alone as planting material was higher (82.2 and 52.2%) than both seed and seedlings (17.8 and 47.8%) in Kalu and Dawa Chefa districts, respectively. The use of seedlings (tillers) alone as planting material was not practiced in both study areas. Those planting materials were mainly obtained from government

institutions (67.8 and 74.4%) and other NGOs (38.9 and 45.6%) in Kalu and Dawa Chefa districts, respectively. However, the contribution of farmers to farmers as a source of planting material was very minimal (2.2 and 5.6%) in Kalu and Dawa Chefa districts, respectively.

In both study areas, the major crops planted along with Mulato II and *D. intortum* were sorghum and maize. On the other hand, only 4.4 and 9% of respondents participated in the cultivation of Mulato II and *D. intortum* forages besides to the production in association with PPT in Kalu and Dawa Chefa districts, respectively. Moreover, the production of Mulato II and *D. intortum* in the study areas was mainly dependent upon rain fall. As a result, all respondents in Kalu district and the majority of the respondents (98.9%) in Dawa Chefa district, largely rely on water availability during the main rainy season (June-mid September). Furthermore, the majority of respondents (95.6 and 91.1%) used to harvest Mulato II and *D. intortum* during dry season (October-January) in Kalu and Dawa Chefa districts, respectively; but, the practice of harvesting those forages in the short rainy season (February-May) was almost negligible in both study areas.

Table 4.4. Mulato II and *D. intortum* production

Description	Kalu N (%)	Dawa Chefa N (%)
Farmers experience		
Yes	53 (58.9)	67 (74.4)
No	37 (41.1)	23 (25.6)
Planting materials		
Seed only	74 (82.2)	47 (52.2)
Seed and seedling	16 (17.8)	43 (47.8)
Sources of planting materials		
Government institutions	61 (67.8)	67 (74.4)
NGOs	35 (38.9)	41 (45.6)
Farmers to farmers	2 (2.2)	5 (5.6)
Crops planted with Mulato II and <i>D. intortum</i>		
Sorghum	65 (72.2)	60 (66.7)
Maize	44 (48.9)	64 (71.9)
Alone	4 (4.4)	8 (9)
Planting season		
Main rainy season (June-mid September)	90 (100)	89 (98.9)
Dry season (October-January)	-	2 (2.2)
Harvesting season		
Short rainy season (February- May)	-	1 (1.1)
Main rainy season (June-mid September)	4 (4.4)	7 (7.8)
Dry season (October-January)	86 (95.6)	82 (91.1)

N= number of respondents

4.3.6. Farmers' management practices of Mulato II and *D. intortum*

Various management practices were used in Mulato II and *D. intortum* production (Table 4.5). Application of fertilizer and weeding at the time of weed infestation were farmers' management practices in both study areas although the extent was very limited. In this study, about 28.9 and 43.3% of the respondents apply fertilizer to Mulato II and *D. intortum* in Kalu and Dawa Chefa districts, respectively. Those respondents who apply fertilizer were found to apply the organic one (manure) in both study areas. The application of inorganic and/or both types (organic and inorganic) were not practiced in both districts. In addition, weeding was not practiced by the majority of respondents (70 and 61.1%) in Kalu and Dawa Chefa districts, respectively, only small number of respondents practiced weeding (Kalu: 30 and Dawa chefa: 38.9%).

Table 4.5. Farmers' management practices of Mulato II and *D. intortum* production

Descriptions	Kalu	Dawa chefa	Overall
	N (%)	N (%)	
Fertilizer application			
Yes	26 (28.9)	39 (43.3)	65 (36.1)
No	64 (71.1)	51 (56.7)	115 (63.9)
Fertilizer applied			
Organic	26 (28.9)	39 (43.3)	65 (36.1)
Practice weeding			
Yes	27 (30)	35 (38.9)	62 (34.4)
No	63 (70)	55 (61.1)	118 (65.6)

N= number of respondents

4.3.7. Purposes and challenges of Mulato II and *D. intortum* production

The purposes and challenges of Mulato II and *D. intortum* production are presented in Table 4.6. All respondents used Mulato II and *D. intortum* forages as pest management and animal feed in both study areas followed by soil conservation. Very few respondents (7.8 and 14.4%) reported that they were used those forages as cash source in Kalu and Dawa Chefa districts, respectively. Despite the contribution of Mulato II and *D. intortum* to the farming system, the production is yet influenced by several factors. As perceived by the respondents, the major challenges were land scarcity, shortage of seed/planting materials, prick and stick with cloths for *D. intortum*, leaf shuttering, difficulty to clear land while needed especially for *D. intortum* and lack of awareness in both study areas.

Table 4.6. Purposes and challenges of Mulato II and *D. intortum* production

Descriptions	Kalu	Dawa Chefa	Overall
	N (%)	N (%)	
Purpose of Mulato II and <i>D. intortum</i>			
Pest management	90 (100)	90 (100)	180 (100)
Livestock feed	90 (100)	90 (100)	180 (100)
Soil conservation	53 (58.9)	78 (86.7)	131 (72.8)
Cash source	7 (7.8)	13 (14.4)	20 (11.1)
Challenges associated with Mulato II and <i>D.intortum</i>			
Land scarcity	90 (100)	90 (100)	180 (100)
Shortage of seed/planting material	90 (100)	90 (100)	180 (100)
Pricks and stick with cloths	90 (100)	90 (100)	180 (100)
Leaf shuttering problem (<i>D.intortum</i>)	88 (97.8)	86 (95.6)	174 (96.7)
Lack of awareness	82 (91.1)	85 (94.4)	167 (92.8)
Difficulty to clear land while needed	87 (96.7)	90 (100)	177 (98.3)

N= number of respondents

4.4. Discussion

4.4.1. Socioeconomic characteristics of respondents

The study assessed the overall production and utilization practices of Mulato II and *D. intortum* forages by smallholder farmers. Education is the other variable which tends to raise household income through technological advances. However, most of the interviewed farmers were illiterate (Kalu: 72.2 and Dawa Chefa: 53.3%), making it difficult for them to adopt new agricultural technologies. This, in turn, limits the production of those forages. In contrast to the present result, Hassen *et al.* (2019) reported that about 43.6% of respondents were able to read and write, and 22.5% of respondents had gone to primary school in Eastern Amhara Regional State, Ethiopia. The productivity of the agricultural sector in Ethiopia in general is very low due to low adoption and application of improved agricultural technologies (Beshir, 2014). Thus, the low level of education attainment in study areas could highly hinder agricultural output (Ninh, 2021). Moreover, family size could have positive as well as negative impacts on the livelihood of farmers. On one hand, it is an opportunity to help farmers accomplish various laborious farm activities. On the other hand, the large family size could bring a negative effect on the food security of the family (Gebissa and Geremew, 2022). The family size of Dawa Chefa (6.49) in the current study slightly agreed with the result (6.8) reported by

Asmare and Mekuriaw (2019) in Northwestern Ethiopia. While the family size of Kalu (5.93) coincides with the figure (5.45) reported by Shumetie and Mamo (2019). Contrary to this finding, a higher family size (7.3) was reported by Chufa *et al.* (2022) in Derashe special district. This variation could be due to lack of awareness on proper family planning methods (Mengistu *et al.*, 2021a).

Family size in turn affects the land holding. The land holding per household in both districts was greater than the previous assessment result (0.75 ha) in Kalu and the national average (1.09 ha) for the Amhara Region reported by Lakew *et al.* (2021) and Headey *et al.* (2014), respectively. Besides, the proportion of land allocated for grazing land, fallow land, and cultivated fodder land was very small due to land scarcity as a result of population growth. Less land allocation for forage production could result in the shortage of livestock feed.

4.4.2. Feed shortage mitigation strategies

Understanding feed shortage mitigation strategies is important for animal nutritionists and livestock producers to identify various intervention options that enhance the productivity of livestock. The feed shortage mitigation mechanisms indicated in this study coincides with that of Duguma and Janssens (2021) who reported purchasing roughage as a major feed shortage coping strategy. In contrast to the results of this study, crop residues were used by a lower proportion of farmers in selected districts of Jimma zone (Duguma *et al.*, 2017). The authors argued that lack of awareness on their importance and lack of land for crop production were the main factors associated with the lower contribution of crop residues as a feed shortage mitigation strategy. According to the interviewed farmers, the use of concentrate as a feed shortage mitigation strategy was the least preferred option. They believed that these feed resources were not accessible or affordable to many farmers.

Moreover, the production and contribution of improved forage crops as a feed shortage mitigation strategy in the farming system are very limited elsewhere in the region (Workye *et al.*, 2018; Gashe, 2022). According to Gebeyew *et al.* (2016), improved forage cultivation was not common in Dawa Chefa district. The authors

contended that limited extension work, lack of information and absence of improved forage seeds were the major constraints for production. Compared to the current study, similar improved forage types were cultivated in Kalu district (Tegegne and Assefa, 2010). The fact that *Sesbania Sesban* and *Pennisetum Purpureum* cultivated by the majority of the respondents in the current study could be attributed to the suitability of the forages as a fence and backyard forage development strategy.

4.4.3. Utilization practices of improved forages

Identifying the utilization practices of improved forages is essential for sustainable livestock production. The practice of utilizing green fodder/cut and carry system to feed their livestock by the majority of respondents in both study areas is in line with previous findings of Zeru and Lijalem (2016) and Tefera *et al.* (2019) in Wolaita zone and Farta district, respectively. Cut and carry feeding system is practiced when the feed resources are available in protected (enclosure) areas, soil conservation structures and crop lands (Tefera *et al.*, 2019). The practice of using hay and silage was negligible in the two study areas as a result of the lower quantity of forages produced in their farming system. This, in turn, could be due to the very small land allocated for forage cultivation. In fact, the production and utilization of improved forages are influenced by many factors. A survey study conducted in Damot Gale district of Wolaita zone revealed that improved forage production was hampered by planting material and land shortage (Mengistu *et al.*, 2021a). Besides, farmers were complained that improved forage production resulted in land competition which supposed to be used for food crop production. As a result, the production and utilization of improved forages are constrained due to unavailability of additional land for forage establishment.

4.4.4. Production, utilization, and constraints of Mulato II and *D. intortum* forages

Mulato II and *D. intortum* forages play a significant role in livestock feeding beyond their primary function in crop pest management. These forage species were used in PPT especially in sorghum and maize fields to control crop pest. As a win-win advantage, these forage species were also used as livestock feeding. As mentioned by the farmers, the main production strategies of Mulato II and *D. intortum* were predominantly

in the border of push pull technology. In both study areas, only fewer farmers had cultivated Mulato II and *D. intortum* in backyard and soil bunds, roadside and stock exclusion areas in addition to PPT due to the unavailability of adequate land.

The planting materials used for Mulato II and *D. intortum* in both study areas were seed followed by both seed and seedlings or tillers. The interviewed farmers perceived that using seedlings or tillers as a planting material was tedious and laborious work and more costly compared to seed. Consequently, the use of seedlings (tillers) alone as planting material was not practiced in both study areas. This finding is in line with the report of Adnew *et al.* (2018) who indicated that about 51.8% respondents used seed as a planting material. Unlike this result, it has been noted that desho grass was planted using root splits (Leta *et al.*, 2013).

The farmers indicated that sorghum and maize were the major crops planted along with Mulato II and *D. intortum* in both study areas. This might be due to the fact that those forages were mainly used in association with push-pull technology (PPT) to control cereal crop pests. The push-pull system was first developed and promoted by the International Centre of Insect Physiology and Ecology (ICIPE) (Dhakal and Islam, 2018). In addition, the production of Mulato II and *D. intortum* in both study areas was mainly dependent upon rainfall. This might be due to the lack of irrigation practices for the cultivation of crops such as maize and sorghum during the dry season. This finding is in agreement to the figure reported by Serekebrhan *et al.* (2018) who found that about 73.3% of the respondents were dependent on rain to produce forage crops in the central highlands of Ethiopia. Beyond this, the majority of farmers harvested Mulato II and *D. intortum* forages during the dry season (October-January) due to the association of those forages with cultivated crops. Supporting this study, the majority of the respondents (74.6%) reported that harvesting of Mulato II grass was done four months after establishment (Adnew, 2018).

The success of Mulato II grass and *D. intortum* production largely depends on farmers' management activities. As indicated by the majority of farmers, the application of fertilizer to Mulato II grass was not adequate mainly during establishment. Only a

small number of farmers apply organic fertilizer (manure) since the cost of inorganic fertilizer is skyrocketed. In line with this study, it has been reported that the involvement of farmers in fertilizer application for forage cultivation was very low (Zeru and Lijalem, 2016; Abera *et al.*, 2021). Inconsistent with the current study however, the majority of the respondents (58.3 and 64.5%) were found to use either natural or commercial fertilizer on desho grass in Burie Zuria and Doyogena districts, respectively (Asmare *et al.*, 2016). Moreover, the poor participation of farmers in weeding of Mulato II and *D. intortum* could be due to the family members spending much of their time on the management of food crops instead of weeding forages. Farmers also argued that lack of awareness was another hindering factor for management of Mulato II and *D. intortum* in both study areas.

Although farmers' management practices of Mulato II grass and *D. intortum* production were poor, they exploited those forages for various purposes. The advantages of Mulato II as pest control (38%) and animal feed (36%) were reported in East Africa (Cheruiyot *et al.*, 2020). Respondents also mentioned that soil conservation was the other contribution of those forage species in both study areas. The use of those forages in soil conservation was higher in Dawa Chefa compared to Kalu district due to the relatively good experience in the production of forages and the good acceptance of the limited extension services. Further, the very low utilization of Mulato II grass and *D. intortum* as a cash source by interviewed farmers in the current study could be due to the lower amount of forage produced on their farmlands. As a result, only very few farmers who produced relatively higher yield involved in marketing of those forage species to urban livestock producers. In accordance with this observation, Dereje *et al.* (2020) found that only smaller numbers of respondents (13.3%) used improved forages as a source of income generation in Amuru district. In addition, Njuguna-Mungai *et al.* (2022) noted that introduced fodders were not used as a traded commodity in Ethiopia. The authors argued that the plots of land allocated to improved forages were very small (0.01 ha on average).

Though Mulato II grass and *D. intortum* provide farmers with a multitude of advantages, the production of these forages in both study areas has been challenged by several factors. The lack of seed/ planting material in both study areas is probably due to its high cost which was not easily afforded by the resource constrained farmers. With respect to this view, studies have shown that the unavailability of *Brachiaria* seeds in local retail agents (Cheruiyot *et al.*, 2020) and the shortage of *D. intortum* seed (Khan *et al.*, 2014) were reported to be the major constraints of Mulato II grass and *D. intortum* production.

4.5. Conclusion and Recommendations

Cultivation of improved forages in the farming systems is one way out of the present feed shortage crisis. Use of multipurpose improved forages such as Mulato II and *D. intortum* could be a prominent solution having a win-win advantage. Those forage species were used in push-pull technology in one hand to increase crop yield and in another hand to produce livestock feed. In both study areas, farmers were mainly dependent on main rainy season to produce Mulato II and *D.intortum* and application of fertilizer and weeding were very limited. Cut and carry system was the common utilization practice by farmers to feed Mulato II and *D. intortum* to their livestock in both study areas. Farmers had utilized Mulato II and *D. intortum* as livestock feed, pest management, and soil conservation. In both study areas, land scarcity and shortage of seed/planting material were the major hindering factors for the production of Mulato II and *D. intortum*.

This study provides a key lesson to various stakeholders such as governmental institutions to undertake strong extension services and provision of planting materials. In general, measures such as technical, institutional and technological interventions are suggested to help farmers increase their knowledge and perceptions about the production and utilization of Mulato II and *D. intortum*. Farmers could be assisted through training, workshops, and providing planting materials to avert the existing feed shortage.

CHAPTER 5: MORPHOLOGICAL CHARACTERISTICS, YIELD AND NUTRITIVE VALUE OF MULATO II AND *Desmodium intortum* INFLUENCED BY PLANTING PATTERN, AGROECOLOGIES AND HARVESTING AGES

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Abstract

This study evaluated the morphological characteristics, yield, and nutritive value of Mulato II and *Desmodium intortum* as influenced by planting pattern (sole Mulato II, sole *D. intortum* and intercropped Mulato II with *D. intortum*), agroecologies (low and midland), and harvesting times (90 and 120 days) under rain fed condition. The study used randomized complete block design in a factorial arrangement with three factors (planting pattern, agroecologies, and harvesting ages) replicated thrice. Except for land equivalent ratio, most morphological characteristics (PHPP, NTPP, NLPP, LLPP, LSR, NRPP, NBPP, and NRNPP) were significantly affected ($P < 0.05$) by the interaction effect of planting pattern, agroecologies and harvesting ages. The longest plant height (132.3 cm), the highest tiller number (68.7), leaf number (537.6) and root number (303.4) were measured from the intercropped Mulato II at 120 days in the lowland agroecology. The highest branch number (32.3) and number of root nodules (286) for *D. intortum* were obtained from sole stand at 120 days in the lowland. Similarly, the Ash, CP, NDF for Mulato II, ADL, ADL for Mulato II, and IVDMD contents were significantly ($P < 0.05$) affected by the interaction effect of planting pattern, agroecologies and harvesting ages except NDF and ADL for *D. intortum* and metabolizable energy (ME) for both Mulato II and *D. intortum*. The highest CP (12.3%) for Mulato II was recorded from the

intercropped which was harvested at 90 days in lowland. The highest dry matter yield (DMY) (17.04 and 16.7 t/ha) was recorded from both intercropped Mulato II and *D. intortum*, respectively, harvested at 120 days in lowland. In conclusion, optimum DMY and CP value of Mulato II and *D. intortum* were obtained from the intercrop harvested at 120 days in the low altitude.

Keywords: Brachiaria, Desmodium, planting pattern, agroecology, agronomic performance, nutritive value

5.1. Introduction

Insufficient and low-quality feeds is a major hindering factor which affects livestock productivity (Tonamo *et al.*, 2015; Schiek *et al.*, 2018). To cope with the existing poor quality and limited availability of feeds, the development and use of improved forages varieties of grasses and legumes having high herbage yield and nutritional values is one of the promising options (Boote *et al.*, 2022).

In relation to introduction, selection and evaluation of improved forage varieties of grasses and legumes, several studies have been conducted in different agroecologies of Ethiopia since 1972. Nowadays, various species of Brachiaria grass have been introduced and utilized by many farmers in eastern Africa (Cheruiyot *et al.*, 2020; Maina *et al.*, 2020). Mulato II (hybrid of *Urochloa ruziziensis*, *U. brizantha* and *U. decumbens*) is among the potential Brachiaria grass species. Currently, its agronomic and chemical composition (Tadesse *et al.*, 2021; Worku *et al.*, 2021) and feeding value (Adnew *et al.*, 2021) were evaluated as a monoculture in Ethiopia.

From the perspective of planting pattern, growing legumes with grasses has manifold advantages than the monoculture (Li *et al.*, 2020). *Desmodium intortum* is one of the most important forage legumes which is suitable for intercropping with grasses (Heuzé *et al.*, 2017). Land shortage in Ethiopia has been a critical challenge because of an alarmingly increasing human population; intercropping could be used as mitigation of such a constraint. The higher productivity of forage and fodder crop under herbaceous legumes–napier grass (Menbere *et al.*, 2015) and vetch–Napier grass (Gelayenew *et al.*,

2020) intercropping systems has been reported in Ethiopia. Higher crude protein (Gelayenew *et al.*, 2020) and dry matter yield (Tesfaye, 2019) were reported when vetch was intercropped with Napier and desho grasses, respectively. Sufficient forage protein from potential intercrops would thus reduce the need for protein supplementation to ruminants and other associated costs (Omokanye *et al.*, 2020).

Apart from its effect on yield and quality of forages, intercropping has also a major role to play in climate smart agriculture. It is obvious that chemicals (inorganic fertilizers, pesticides, herbicides, and fungicides) are the major inputs in agriculture which resulted in compromised soil health, water and air quality. Grass-legume intercropping reduces the use of nitrogen fertilizer input (Luce *et al.*, 2015) and efficiently controls crop pests and weeds (Zuo *et al.*, 2015) and soil erosion (Nyawade *et al.*, 2019). Nevertheless, no information has been documented about Mulato II and *D. intortum* intercropping in Ethiopia. Investigating grass-legume combination would enrich the establishment of more productive crop-livestock integration systems (Santos *et al.*, 2022) since intercropping may or may not favor the resultant forage yield as a result of competition for nutrients (Pinto *et al.*, 2022).

In addition to grass-legume intercropping (Santos *et al.*, 2022), the quantity and quality of forage is affected by several other factors viz. soil fertility and agroecology (Walie *et al.*, 2022) and maturity stage (Seleiman *et al.*, 2017). The yield and quality of forages varied according to the environmental conditions such as soil fertility, rainfall pattern, and ambient temperature. Maturity at harvest is another key factor that affects the yield and quality of cultivated forages. The CP and IVDMD values of forages are high at early harvesting age, but fiber contents are high at delayed harvesting age (Mijena *et al.*, 2022). Yet, information is scanty about the productivity and nutritive value of Mulato II and *D. intortum* forages in response to those factors in Ethiopia. Thus, this study was conducted to evaluate the effect of planting pattern, agroecologies and harvesting ages on herbage yield and nutritive potential of Mulato II and *D. intortum* forages.

5.2. Materials and Methods

5.2.1. Description of study areas

The field experiment was conducted in rainfed conditions in two selected areas of Amhara region, Ethiopia. These areas were selected to represent the compatible altitude for their sole production. The areas were Metema and North Mecha districts which represents the low and mid agroecologies, respectively. Metema is one of the districts in West Gondar Zone of Amhara Regional State. Geographically, it is located between 12°19'19" and 13°27'08" N latitude and 35°51'20" and 36°49'44" E longitude. It is found at 925 km northwest of Addis Ababa and 180 km west of Gondar town. The altitude of the district ranges from 550 to 1068 m.a.s.l. Gendawuha is the capital of the district. The altitude of Gendawuha is 774 m.a.s.l. Mean annual temperature ranges from 22 to 28 °C and daily temperature reaches as high as 43 °C from March to May. Mean annual rainfall ranges from 850 to 1100 mm and has uni-modal pattern. The rainy months extend from June to end of September. According to Desalew (2008), the major soils of the area are Luvisols, Vertisols, Nitosols and Cambisols in descending order of proportion.

North Mecha district is found at 30 kms southwest of Bahir Dar city, the capital of Amhara Region which is geographically located at 9°23' to 9°26' N latitude and 41° 59' to 42°02' E longitude. The altitudinal range of the area spills from 1840-1970 m.a.s.l. The major soils of the area comprised of 93% red, 3% black and 4% grey (Getahun, 2015). The mean annual minimum and maximum temperatures are 10 and 27 °C, respectively. The mean annual rainfall of the area ranges from 1000-2000 mm.

5.2.2. Experimental design, treatments and management

The experiment was conducted in Metema and North Mecha districts. The land was ploughed and prepared in May and harrowed to make fine bed in June in each of the two locations (lowland and midland agroecologies). The fine prepared bed was made to contain three blocks and within each block, there were 6 plots, a total of 18 plots per location. The net plot size was 6m² in each of the two locations. The experiment was laid out in factorial arrangement using a randomized complete block design (RCBD) with

three replications. The treatments were combined with three factors (planting pattern, agroecologies and harvesting ages) into 2*2*2. The treatments had Mulato II and *D. intortum* forages sole or intercropped at two harvesting ages (90 and 120 days) that were accommodated in two locations (low and midland agroecologies).

The planting material for Mulato II was collected from the research site of Andassa Livestock Research Center, while that of *D. intortum* was obtained from Chagni Cattle Breeding and Improvement Ranch. Vegetative root splits were used for planting Mulato II while, root cutting for *D. intortum*. Planting was done during the main rainy season. The intra and inter-row spacing were 50 and 30 cm, respectively for Mulato II grass. The spacing between plot and block was 0.5 and 1m, respectively. *D. intortum* was planted between rows of Mulato II while intercropping. For pure stand *D. intortum*, row spacing of 25 cm was maintained (Bayble *et al.*, 2007). Management practices such as planting, weeding, and harvesting were made according to the recommendations made by Nguku (2016). At planting, inorganic fertilizers, N and P were applied across all plots uniformly at a rate of 64 kg ha⁻¹ for N, and 20 kg ha⁻¹ for P in the form of urea and Diammonium phosphate (DAP) as a starter for establishment for Mulato II grass (Worku *et al.*, 2021).

5.2.3. Data collection and forage sampling

The data on morphological and yield parameters were recorded at each harvesting period for each forage species separately. Ten plants were randomly selected in the middle of each plot to record some of the morphological characteristics. Plant height per plant (PHPP), leaf length per plant (LLPP), and length of roots per plant (LRPP) were measured with measuring tape. The number of tillers per plant (NTPP), number of leaves per plant (NLPP), and number of roots per plant (NRPP) at each harvesting ages in both locations for Mulato II grass were computed as mean of counts. The plant height per plant (PHPP), number of branches per plant (NBPP), and number of root nodule (NRN) measurements for *D. intortum* were treated similarly. The leaf to stem ratio (LSR) for Mulato II and dry matter yield (DMY) for both *D. intortum* and Mulato II forages were also determined.

5.2.3.1. Plant height

Plant height was taken immediately before the time of biomass harvest at each harvesting ages. A measuring tape was used to measure the plant height. The mean plant height for each treatment was recorded by measuring the heights of 10 randomly selected plants per plot from ground level to the upper leaves of the main stem.

5.2.3.2. Number of tillers, leaves and leaf length per plant

The number of tillers per plant and number of leaves per plant of Mulato II were counted from 10 randomly selected plants at each harvesting time and the average count was taken for each parameter. The number of branches per plant of *D. intortum* was determined by counting the branches of 10 randomly selected plants and average count was taken. Leaf length per plant of Mulato II was measured by tape meter from the base of the collar region of the leaf to the tip of the leaf and average was taken from 10 randomly selected plants at each harvesting time.

5.2.3.3. Number and length of roots per plant

After completing data collection on shoot morphological characteristics, the number and length of roots per plant were determined as these roots play vital role to fetch nutrients from the soil. The roots from randomly selected plants were collected and carefully soaked into a bucket of water to clean up from any residual soil and other debris at each harvesting age. Then, the numbers of roots per plant was counted and the mean was computed. The length of root was measured from the crown to the tip of the root and the mean was calculated from five randomly selected plants. For *D. intortum*, the number of root nodules per plant was also counted from randomly selected plants and the mean count was taken.

5.2.3.4. Leaf to stem ratio and dry matter yield

The forage samples were harvested from the middle rows in each of the plots through hand using sickle leaving a stubble height of about 5-10 cm. The leaf to stem ratio of Mulato II was determined by harvesting 10 randomly selected plants. The fresh stems and leaves were weighed separately at each harvesting ages and dried at 65 °C in a

forced air draft oven for 72 hours and then, leaf to stem ratio was computed by dividing leaf dry weight to stem dry weight.

The dry matter yield was determined at the end of each harvesting ages. A fresh weight of the harvested herbage was weighed in each plot soon after mowing, using a field sensitive spring balance; then sub-samples of 500g fresh weight was taken for each plant species, separately, from each plot. The dry weight percentage was computed as sample dry weight divided by sample fresh weight times 100. The dry matter yield was determined according to James *et al.* (2008) as follows:

$$\text{Yield (t/ha)} = \frac{10 \times \text{TFW} \times \text{SSDW}}{\text{HA} \times \text{SSFW}}$$

Where, 10= a constant for conversion of yields in kg m⁻² to t ha⁻¹

TFW= total fresh weight (kg)

SSDW= sub-sample dry weight (g)

HA= harvest area (m²)

SSFW= sub-sample fresh weight (g)

Further, crude protein yield (CPY) was calculated as the product of DMY with CP content divided by 100.

5.2.3.5. Land equivalent ratio (LER)

LER indicates the efficiency of intercropping compared to monocropping (Mead and Willey, 1980). A LER value greater than one indicates the intercropping favors the growth and yield advantage of the species. On the other hand, LER value less than one shows the growth and yield disadvantage. The land equivalent ratio (LER) was estimated according to Willey and Osiru (1972):

$$\text{LER} = \frac{\text{Y}_{\text{Mint}}}{\text{Y}_{\text{Msol}}} + \frac{\text{Y}_{\text{Dint}}}{\text{Y}_{\text{Dsol}}}$$

Where, Y_{Mint}= Yield of Mulato II under intercropping condition

Y_{Msol}= Yield of Mulato II under sole crop condition

Y_{Dint}= Yield of *D. intortum* under intercropping condition

Y_{Dsol}= Yield of *D. intortum* under sole crop condition

5.2.4. Forage sample collection and preparation for chemical analysis

For chemical analysis of forages, the samples were taken by cutting the forages which were found within a 1*1 meter quadrat using sickle and then, a sample of 500g on fresh basis was used for each species (Mulato II and *D. intortum*) at each harvesting ages in both locations. Then, the sample was dried under shade to reduce the moisture content to a safe level for storage until it was brought to Bahir Dar University, animal nutrition laboratory. The partial dry matter was done by drying the forage sample in an oven at 65 °C for 72 hours. Then, the samples were separately ground in a mill to pass through 1 mm sieve size. Thereafter, the samples were kept in air tight plastic bags pending further analysis.

5.2.5. Chemical analysis

The chemical analysis was performed in Holeta animal nutrition laboratory. DM and ash contents of forage samples were determined following the procedure of AOAC (2005). The dry matter content for each forage species was determined by drying the sample in forced draft oven at 105 °C overnight. Ash was determined by complete burning or igniting forage sample in a muffle furnace at 550 °C for three hours. Kjeldhal procedure (AOAC, 2005) was used to determine total nitrogen (N) and crude protein was calculated as $N \times 6.25$. Acid detergent fiber (ADF), neutral detergent fiber (NDF) and acid detergent lignin (ADL) were analyzed according to Van Soest *et al.* (1991).

5.2.6. *In vitro* dry matter digestibility analysis

The *in vitro* dry matter digestibility of the forages was determined according to the procedure of Tilley and Terry (1963). Forage samples dried at 65 °C were ground to pass through 1 mm sieve size. The rumen fluid was taken using a stomach tube from three sheep fed concentrate mixture (Wheat bran: 50%; noug seed cake: 25%; Soybean meal: 15%; maize grain: 10%) based on natural pasture hay basal diet. The rumen fluid was poured into a prewarmed thermos flask containing a cheesecloth and immediately taken to the laboratory. Then after, a duplicate sample of 0.5 gram each and blank samples with buffered rumen fluid were incubated with 30 ml of rumen liquor in 100 ml test tube inside a water bath. The temperature of the bath was adjusted to 39 °C and the

period of incubation was 48 hours for microbial digestion. Incubation for additional period of 48 hours was then followed for enzymatic digestion using acid pepsin solution. Samples were dried at 105 °C for 24 hours. After IVDMD determination, the samples were ashed to calculate *in vitro* organic matter digestibility. The ME (MJ/Kg DM) was determined according to the procedure indicated by NRC (2001):

$$\text{ME (MJ/Kg DM)} = 0.82 * \text{DE} * 4.184$$

$$\text{Where, DE (Mcal/Kg DM)} = [0.01 * (\text{OM}/100) * (\text{IVOMD} + 12.9) * 4.4] - 0.3$$

5.2.7. Statistical analyses

Data on morphological characteristics, yield and chemical composition were subjected to ANOVA using GLM procedure of SAS software version 9.4. Significant differences between individual means at $P < 0.05$ was declared using least significant difference (LSD).

The model used for the analysis of morphological characteristics, yield and chemical composition of the candidate forages was:

$$Y_{ijk} = \mu + T_i + A_j + H_k + T_i * A_j + T_i * H_k + A_j * H_k + T_i * A_j * H_k + \varepsilon_{ijk}$$

Where, Y_{ijk} = dependent variables (data on morphology, forage yield and chemical composition)

μ = Overall mean

T_i = Treatment effect (planting pattern effect)

A_j = effect of agroecologies (lowland and midland agroecologies)

H_k = effect of harvesting ages (90 and 120 days)

$T_i * A_j$ = interaction effect of planting pattern and agroecologies

$T_i * H_k$ = the interaction effect (planting pattern and harvesting ages)

$A_j * H_k$ = interaction effect of agroecologies and harvesting ages

$T_i * A_j * H_k$ = three-way interaction (planting pattern, agroecologies, and harvesting ages)

ε_{ijk} = residual error

5.3. Results

5.3.1. Morphological characteristics of Mulato II and *D. intortum*

The performance of morphological characteristics in Mulato II and *D. intortum* forages as affected by planting pattern, agroecologies and harvesting ages are shown in Table 5.1. Significant effect of interaction ($P < 0.05$) was observed in almost all morphological parameters (PHPP, NTPP, NLPP, LLPP, LSR, NRPP, LRPP for Mulato II, NBPP and NRNPP for *D. intortum*) of the forage plants except for LER for intercropping *D. intortum*. The longest PHPP (132.3 cm) was measured from mixed stand Mulato II at 120 days to harvest in lowland agroecology, while the shortest (81.7 cm) was recorded from sole Mulato II at 90 days in the midland agroecology. Sole stand *D. intortum* had higher PHPP (170.7 cm) at 120 days in the lowland agroecology as compared to the PHPP (96.3 cm) measured from sole stand *D. intortum* harvested at 90 days in the midland agroecology.

The largest NTPP (68.7) and NLPP (537.6) were counted from the intercropped Mulato II at 120 days to harvest in the lowland agroecology, whereas the smallest NTPP (31.2) and NLPP (201.9) were counted from sole Mulato II at 90 days to harvest in the midland. Besides, sole *D. intortum* had the largest count of NBPP (32.3) at 120 days of harvesting time in the lowland agroecology, while the lowest count (18.8) was obtained from mixed stand *D. intortum* at 120 days of harvesting time in the lowland agroecology.

The longest LLPP (42.6 cm) was measured from intercropped Mulato II at 120 days in the lowland agroecology. Mulato II intercropped with *D. intortum* had the highest LSR (2.57) at 90 days to harvest in the lowland agroecology. In addition, the highest NRPP (303.4) was counted from mixed stand Mulato II at 120 days harvest in lowland agroecology; but, lowest NRPP (113.7) was recorded from sole Mulato II at early stage of harvesting (90 days) in the midland agroecology. On top of this, the largest NRNPP (286) was counted from sole stand *D. intortum* at 120 days of harvesting age in the lowland agroecology, but the lowest count (178.9) was observed from mixed stand *D. intortum* at 90 days of harvest in the midland agroecology.

Table 5.1. Effect of planting pattern, agroecologies, and harvesting ages and their interaction on the morphological characteristics of Mulato II and *D. intortum*

Factors			PH (cm)		NT (count)	NLPP (count)	LLPP (cm)	LSR	NRPP (count)	LRPP (cm)	NB (Count)	NRN (Count)	LER
PP	Agec	HA	Mullato II	DI	Mulato II				<i>D. intortum</i>				
Sole	Low	90	103.4 ^{cd}	121.7 ^b	46.5 ^d	339.6 ^c	35.4 ^d	1.50 ^c	180.7 ^d	24.9 ^c	22.2 ^d	197.4 ^b	-
		120	121.8 ^b	170.7 ^a	57.9 ^b	434.6 ^b	40.3 ^{abc}	1.29 ^{cd}	234.7 ^b	36.2 ^a	32.3 ^a	286.0 ^a	-
	Mid	90	81.7 ^f	96.3 ^c	31.2 ^f	201.9 ^f	35.4 ^d	1.85 ^b	113.7 ^g	26.0 ^c	25.3 ^b	198.0 ^b	-
		120	112.4 ^{bc}	166.2 ^a	41.2 ^e	262.4 ^e	38.0 ^{bcd}	1.13 ^d	146.3 ^f	31.7 ^b	29.3 ^b	204.4 ^b	-
Int	Low	90	105.7 ^c	122 ^b	52.7 ^c	443.3 ^b	37.2 ^{cd}	2.57 ^a	186.5 ^d	31.7 ^b	21.9 ^d	188.0 ^b	1.84
		120	132.3 ^a	169.1 ^a	68.7 ^a	537.6 ^a	42.6 ^a	1.47 ^c	303.4 ^a	39.0 ^a	18.8 ^e	203.2 ^b	2.43
	Mid	90	91.3 ^{ef}	115.3 ^b	51.5 ^c	302.8 ^d	36.3 ^d	2.06 ^b	160.7 ^e	37.3 ^a	22.1 ^d	178.9 ^d	2.09
		120	93.4 ^{de}	165.2 ^a	52.9 ^c	266.3 ^e	40.5 ^{ab}	1.20 ^d	196.3 ^c	38.3 ^a	27.6 ^b	200.4 ^b	2.16
		SE	3.41	5.9	2.21	22.41	0.6	0.1	11.34	1.15	0.9	6.5	0.09
PP*Agec*HA		Sig	***	***	***	***	**	***	***	***	***	***	ns
Mean values	PP	Sole	104.8	138.7	44.2	309.6	37.3	1.44	168.9	29.7	27.3	221.4	-
		Int	105.7	142.9	56.5	387.5	39.2	1.83	211.7	36.6	22.6	192.6	-
		Sig	ns	ns	***	***	*	***	***	***	***	***	-
	Agec	Low	115.8	145.9	56.4	438.8	38.9	1.7	226.3	32.9	23.8	218.6	-
		Mid	94.7	135.8	44.2	258.3	37.6	1.6	154.3	33.3	26.1	195.4	-
		Sig	***	***	***	***	ns	***	***	ns	***	***	-
	HA	90	95.5	113.9	45.5	321.9	36.1	2	160.4	30	22.9	190.6	-
		120	114.9	167.8	55.2	375.2	40.4	1.3	220.2	36.3	27	223.5	-
		Sig	***	***	***	***	***	***	***	***	***	***	-

^{a-f} Treatment means with different letters in a column and category are significantly different ($P < 0.05$). PP=planting pattern, Int= intercropping, Agec= agroecology, HA= harvesting ages; cm: centimeter, PH= plant height, NT= tiller number, NL= leaf number, LL= leaf length, NR= root number, RL= root length, LSR= leaf to stem ratio, LER= land equivalent ratio, DI= *Desmodium intortum*, CV= coefficient of variation, SE=standard error

5.3.2. Chemical composition of Mulato II and *D. intortum* forages

Table 5.2 shows the response of the chemical composition of Mulato II and *D. intortum* as affected by planting pattern, agroecologies, and harvesting ages and their interaction. Except for the NDF and ADL contents of *D. intortum*, almost all of the chemical composition parameters (Ash, CP, NDF for Mulato II, ADF, and ADL for Mulato II) of Mulato II and *D. intortum* were significantly affected ($P<0.05$) by the interaction effect of planting pattern, agroecologies, and harvesting ages. Sole Mulato II had the highest ash content (8.8%) at 90 days of harvesting time in the lowland agroecology. Higher CP content (12.3%) was recorded from intercropped Mulato II at 90 days in lowland agroecology compared to sole stand Mulato II with lower CP value (8.7%) at 120 days in the lowland agroecology. Further, sole stand *D. intortum* had the higher CP value (17.25%) at 90 days of harvesting age in the midland than the intercropped *D. intortum* (11.75%) at 120 days of harvesting age in the lowland agroecology.

Based on the current result, the highest NDF (71.9%) content was recorded from sole Mulato II at 120 days of harvesting age in the lowland agroecology. Lower NDF content was recorded for sole (54.2, 53.3%) and intercropped (54.7 and 55.6%) Mulato II at both harvesting ages (90 and 120) in the midland agroecology, respectively. Mulato II grass had the higher ADF contents (31.8 and 30.4%) from both sole stand and intercropped regimen, respectively, at 120 days of harvesting time in the lowland agroecology. Besides, sole *D. intortum* had higher ADF content (24.8%) at 120 days of harvesting time in the lowland agroecology.

Table 5.2. Chemical composition of Mulato II and *D. intortum* as affected by planting pattern, agroecologies, and harvesting ages and their interaction (% DM, unless specified)

Factors														
PP	Agec	HA	DM		Ash		CP		NDF		ADF		ADL	
			MII	DI	MII	DI	MII	DI	MII	DI	MII	DI	MII	DI
Sole	Low	90	92.0 ^{ab}	90.6 ^c	8.8 ^a	5 ^{abc}	11.6 ^{ab}	14.8 ^{bc}	59.7 ^d	51.8	26.6 ^b	20.4 ^{cd}	3.8 ^c	3.8
		120	91.9 ^{ab}	91.7 ^{abc}	2.5 ^d	5.2 ^a	8.7 ^e	12.9 ^{de}	71.9 ^a	50	31.8 ^a	24.8 ^a	4 ^{abc}	5.4
Int	Mid	90	91.5 ^{bc}	91.4 ^{bc}	6.5 ^b	4.5 ^{abcd}	10.6 ^{bcd}	17.25 ^a	54.2 ^e	47.23	24 ^{bc}	19.3 ^d	3.4 ^c	4.5
		120	92.8 ^a	92.38 ^{ab}	5.6 ^{bc}	3.4 ^d	10 ^d	13.6 ^{cd}	53.3 ^e	49.2	21.2 ^d	23 ^{ab}	4.9 ^{ab}	4.9
	Low	90	91.4 ^{bc}	90.68 ^c	5.9 ^{bc}	4 ^{bcd}	12.3 ^a	14.6 ^{bc}	63.5 ^c	49.78	24.8 ^{bc}	22.4 ^{bc}	3.8 ^{bc}	4.9
		120	92.2 ^{ab}	91.45 ^{bc}	3.4 ^d	3.7 ^{cd}	10.3 ^{cd}	11.75 ^e	67.3 ^b	50.08	30.4 ^a	23.1 ^{ab}	4.3 ^{abc}	5.1
	Mid	90	90.74 ^c	90.37 ^c	6 ^{bc}	5.1 ^{ab}	11.3 ^{abc}	16.04 ^{ab}	54.7 ^e	47.81	23.1 ^{cd}	22 ^{bc}	3.7 ^c	4.1
		120	92.6 ^a	93.1 ^a	4.9 ^c	4.4 ^{abcd}	10.6 ^{bcd}	14.4 ^{cd}	55.6 ^e	49.3	24.6 ^{bc}	24.1 ^{ab}	5.1 ^a	4.4
PP*Agec*HA		SE	0.16	0.23	0.39	0.17	0.25	0.37	1.38	0.57	0.76	0.42	0.16	0.16
		Sig	**	*	***	*	***	***	***	ns	***	**	*	ns
Mean values	PP	Sole	92	91.5	5.9	4.4	10.2	14.7	59.8	49.6	25.9	21.9	4	4.7
		Int	91.8	91.4	5.1	4.3	11.1	14.2	60.3	49.2	25.7	22.9	4.2	4.6
		Sig	ns	ns	**	ns	**	ns	ns	ns	ns	ns	ns	ns
	Agec	Low	91.9	91.1	5.2	4.4	10.7	13.5	65.6	50.4	28.4	22.67	4	4.8
		Mid	91.9	91.8	5.8	4.4	10.6	15.3	54.4	48.4	23.2	22.11	4.3	4.5
		Sig	ns	ns	*	ns	ns	***	***	ns	***	ns	ns	ns
	HA	90	91.4	90.8	6.8	4.6	11.4	15.7	58.0	49.2	24.6	21	3.7	4.3
		120	92.4	92.2	4.1	4.2	9.9	13.2	62.0	49.7	27	23.8	4.6	5
		Sig	**	**	***	ns	***	***	***	ns	***	***	**	ns

^{a-c}Treatment means with different letters in a column and category are significantly different ($P < 0.05$).

PP= planting pattern, Int= intercropping, Agec= agroecologies, HA= harvesting ages, CP= crude protein, NDF= neutral detergent fiber, ADF= acid detergent fiber, ADL=acid detergent lignin, MII= Mulato II, DI= *Desmodium intortum*, CV=coefficient of variation, SE=standard error

5.3.3. DMY, CPY, IVDMD and ME values of Mulato II and *D. intortum* forages

Except for metabolizable energy (ME), the dry matter yield (DMY t/ha), crude protein yield t/ha), and IVDMD responses of Mulato II and *D. intortum* forages were significantly affected ($P<0.05$) by the interaction effect of planting pattern, agroecologies, and harvesting ages (Table 5.3). The highest DMY (17.04 and 16.7 t/ha) were observed from the intercropped Mulato II and *D. intortum* harvested at 120 days in lowland agroecology. Higher CPY (1.69 and 1.76 t/ha) were obtained from the intercropped Mulato II grass at both harvesting ages (90 and 120 days), respectively, in the lowland agroecology. Sole stand Mulato II had the highest IVDMD (70.4%) in the midland agroecology at 90 days. The lowest IVDMD value (62.3%) was obtained from sole stand Mulato II at 120 days in the lowland agroecology. Moreover, the highest IVDMD content (70.16%) was observed from sole *D. intortum* at 90 days harvest in the midland agroecology. Further, the ME content of Mulato II declined (8.8-7.91 MJ/kg DM) as harvesting ages increased from 90 to 120 days.

Table 5.3. DMY, CPY, IVDMD, and ME value of Mulato II and *D. intortum* as affected by planting pattern, agroecologies, and harvesting ages and their interaction

Factors			DMY (t/ ha)		CPY (t/ha)		IVDMD (%)		ME(MJ/kg DM)	
PP	Agec	HA	MII	DI	MII	DI	MII	DI	MII	DI
Sole	Low	90	11.4 ^{cd}	6.5d ^c	1.31 ^b	0.96 ^c	67 ^{bcd}	67 ^b	8.8	8.9
		120	14.4 ^b	13.6 ^b	1.25 ^b	1.76 ^a	62.3 ^e	63 ^e	8	8.2
Int	Mid	90	6.9 ^e	5.5 ^e	0.73 ^d	0.95 ^c	70.4 ^a	70.16 ^a	8	8.9
		120	10.4 ^d	8.8 ^{cd}	1.04 ^{bc}	1.203 ^{bc}	67.3 ^{abc}	64 ^{cde}	7.4	8.6
	Low	90	13.8 ^{bc}	6.8 ^{de}	1.69 ^a	0.98 ^c	65.9 ^{cde}	66 ^{bc}	8.7	8.7
		120	17.04 ^a	16.7 ^a	1.76 ^a	1.94 ^a	63.3 ^{de}	63.6 ^{de}	8.4	7.6
	Mid	90	6.54 ^e	5.96 ^e	0.74 ^{cd}	0.95 ^c	69.7 ^{ab}	65b ^{cd}	9.2	8.4
		120	10.3 ^d	9.8 ^c	1.09 ^b	1.41 ^b	64.2 ^{cde}	64 ^{cde}	7.7	7.9
		SE	0.75	0.82	0.08	0.082	0.67	0.5	0.17	0.14
PP*Agec*HA		Sig	***	***	***	***	**	***	ns	ns
Mean values	PP	Sole	10.8	8.6	1.08	1.22	66.6	66	8.2	8.6
		Int	11.9	9.8	1.32	1.32	65.8	64.6	8.5	8.1
	Agec	Sig	ns	*	**	ns	ns	**	ns	ns
		Low	14.1	10.9	1.5	1.41	64.5	64.8	8.5	8.3
		Mid	8.5	7.5	0.9	1.13	68	65.8	8.2	8.5
		Sig	***	***	***	***	**	*	ns	ns
	HA	90	9.7	6.2	1.12	0.96	68.1	67	8.8	8.7
		120	13	12.2	1.28	1.58	64.3	63.6	7.9	8.1
Sig		***	***	*	***	**	***	**	*	

^{a-c}Treatment means with different letters in a column and category are significantly different ($P < 0.05$). PP=planting pattern, Int=intercropping, Agec= agroecology, HA= harvesting ages, IVDMD= *In vitro* dry matter digestibility, ME= metabolizable energy, MII= Mulato II, DI= *D. intortum*, CV= coefficient of variation, SE= standard error

5.4. Discussion

5.4.1. Morphological characteristics of Mulato II and *D. intortum* forages

The current study was conducted to evaluate the morphological and nutritive potentials of Mulato II and *D.intortum* forage species as influenced by planting pattern, agroecologies, and harvesting ages. The PHPP (81.7 cm) of sole Mulato II at 90 days of harvesting age in the midland agroecology disagreed with the result of Worku *et al.* (2021) who reported lower (37 and 64 cm) PHPP of Mulato II and Mulato I grasses grown in monoculture at 90 days of harvesting age in the midland agroecology of Damote Gale district, respectively. On the other hand, Tiruneh *et al.* (2022) reported

relatively higher PHPP (83.6 cm) for *Brachairia mutica* grown in monoculture in the midland agroecology. Moreover, the PHPP (170.7 cm) measured for *D.intortum* was much higher than the finding of Anteneh, (2022) who recorded a PHPP (60.5 cm) of intercropped silverleaf desmodium at 120 days of harvesting time in the midland agroecology. The result was also higher than the finding of Keba (2023) who showed that sole silverleaf desmodium had PHPP (101.6 cm) at 120 days to harvest in the midland agroecology. The variation in PHPP could partly be due to differences in environmental conditions (Yiberkew *et al.*, 2020) such as soil fertility, ambient temperature, species, method of cropping, and management practices.

Tillering performance is an important morphological characteristic to be considered during selection of appropriate forage crop species for better improvement of production. It is highly associated with forage biomass production (Luna *et al.*, 2016). The NTPP (31.2) and NLPP (201.87) of sole stand Mulato II recorded in this study were inconsistent with that of Hunegnaw *et al.* (2022) who found higher values of NTPP (46) and NLPP (380.9) for Mulato II grown in monoculture that was harvested at 90 days in the midland agroecology. In addition, Keba (2023) reported relatively much higher NTPP (53.6) of sole desho grass at 120 days of harvesting age in the midland agroecology than our finding (NTPP: 41.2) for sole stand Mulato II grass. According to Wangchuk *et al.* (2021), leaves play a pivotal role in food production and act as a basic factory in growing plant. The NLPP (201.87) for sole Mulato II counted in this study disagreed with the results (483.6 and 380.9) reported by Bantihun *et al.* (2022) and Hunegnaw *et al.* (2022) for sole stand brachairia grass at 90 days of harvesting time in the midland agroecology, respectively. The discrepancy in NTPP and NLPP between those studies could be due to variations in soil type and fertility (Walie *et al.*, 2022), temperature, species, and management practices involved during the experiment (Boob *et al.*, 2021).

The change in leaf growth rate seems to be due to an increase in cell division which could be related to environmental regulation of the gibberellins pathway (Barre *et al.*, 2015). The LLPP (42.64 cm) recorded in this study from the intercropped Mulato II grass was higher than the result (15.93 cm) noted by Tiruneh *et al.* (2022) for the same grass cultivar. The disparity could be due to variations in soil type and fertility (Walie *et*

al., 2022), temperature, cropping system (Pentos *et al.*, 2022) and management practices employed under those studies (Yiberkew *et al.*, 2020).

Leaf to stem ratio (LSR) has an impact on the forage quality and palatability. It has also shown to determine diet selection and intake in tropical grasses. The LSR value (2.57) was higher than the leaf to stem ratio (0.93) reported by Adnew *et al.* (2019) for the same cultivar grown in monoculture. According to Wangchuck *et al.* (2021), the variations in LSR between these studies might be due to differences in soil fertility and environmental conditions. Likewise, the management practices such as fertilizer application and spacing applied could bring variations in LSR in Mulato II (Yiberkew *et al.*, 2020).

The highest NRPP (303.4) was counted from intercropped Mulato II with *D. intortum* harvested at 120 days of harvesting age in the lowland agroecology might be attributed to enhanced soil fertility which support dense ground cover and root mass. Compared to the NRPP (113.7) of sole Mulato II, Zemene *et al.* (2020) reported relatively higher NRPP (139.7) for sole stand *Brachairia mutica* grass at 90 days to harvest in the midland agroecology. This variation could be associated with the differences in soil nature, cultivar and management practices undertaken during the experiment. Furthermore, 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 land equivalent ratio (LER) evaluates the land efficiency of intercrop which indicates whether intercropping favors herbage yield or not. The land equivalent ratio observed in the current study was greater than 1 which could imply the yield advantage of intercrop compared to monoculture. This study is comparable with that of Rahman *et al.* (2015) who pointed out that the calculated LER (1-1.84) for high yielding forages was greater than 1, which showed the benefit of intercropping. The same author also stated that intercropping favors the growth and yield of the forages thereby reducing weed distribution, pest and disease infestations.

5.4.2. Chemical composition of Mulato II and *D. intortum* forages

The crude protein content of forage is one of the determinants of its quality and it is an essential nutrient required by ruminant animals. In the current study, intercropping regimen and early harvesting age might contributed to the higher CP value (12.3%) of intercropped Mulato II with *D. intortum*. In line with the CP value (12.3%) for the intercropped Mulato II, Hunegnaw *et al.* (2022) observed comparable CP content (13.04) for sole stand Mulato II. From the perspective of the nutrient requirement of animals, the lowest CP content (8.7%) of Mulato II recorded in this study was not compromised as the value is well above the minimum CP requirement for normal rumen function (7%) (Van Soest, 1994; NRC, 2001). The CP content (17.25%) scored for sole *D. intortum* in this study was comparable with the figure (17.46) reported by Bayble *et al.* (2007) at 90 days of harvesting time in the lowland agroecology, Pawe Agricultural Research Center, Ethiopia.

Dry matter intake and digestibility are known to be affected by the NDF concentration in feeds, the more fibrous feed occupies more space for longer and limits the intake rate (Peprah *et al.*, 2021). In this study, the NDF content (71.9%) for sole Mulato II was higher than the NDF content (65.22%) of sole Mulato II grass reported by Adnew *et al.* (2019) in the South Gondar, Ethiopia. According to Lima *et al.* (2002), high NDF that is above 72% will cause low intake of forage. Thus, the NDF content (71.9%) recorded from sole Mulato II may not hinder intake as such.

The ADF content (31.8%) recorded in the current study is also inconsistent with earlier reports by Zemene *et al.* (2020) who observed higher ADF content (36.6%) for pure stand *Brachairia mutica* at 120 days of harvesting age in the midland agroecology. The discrepancy in fiber content between those studies might be attributed to differences in environmental conditions (Walie *et al.*, 2022), cutting time (Zemene *et al.*, 2020), and management practices such as application of fertilizer (Hunegnaw *et al.*, 2022). On top of this, sole *D. intortum* had numerically higher ADF content (24.8%) at 120 days of harvesting age in the lowland agroecology which disconfirms with the work of Zewdu and Baars (2006) who reported relatively higher ADF content (31.4%) for sole *Desmodium uncinatum*. Abebe (2020) also observed higher ADF content (26%) for

Desmodium dichotomum in the midland areas of Wollo. The disagreement in fiber components of *D. intortum* between studies could also be attributed to differences in environmental conditions (Walie *et al.*, 2022), maturity stage (Adnew *et al.*, 2019; Zemene *et al.*, 2020), and management practices (Yiberkew *et al.*, 2020).

5.4.3. DMY, IVDMD and ME value of Mulato II and *D. intortum* forages

The higher DMY (17.04 and 16.7 t/ha) calculated from intercropped Mulato II and *D. intortum* at 120 days of harvesting age in the lowland agroecology, respectively, could be due to the compatibility in altitude, temperature and soil characteristics. At the later stage of harvesting, a general DMY increase was observed due to the rapid increase in the tissues of the plant, development of additional tillers and leaf formation, leaf elongation and stem development (Tilahun *et al.*, 2017; Molla *et al.*, 2018; Zemene *et al.*, 2020). In addition, the higher dry matter yield could be related to the development of more tillers (Van Soest and Robertson, 1985). In contrary to the DMY (17.04) recorded for intercropped Mulato II in this finding, Tiruneh *et al.* (2022) observed lower DMY (14.2 t/ha) for the sole stand Mulato II grass in the midland agroecology. The variation could probably be due to differences in soil type (Hunegnaw *et al.*, 2022), forage mixture, harvesting age (Molla *et al.*, 2018; Adnew *et al.*, 2019), and management practices (Mijena and Getiso, 2022).

In contrast to our result (62.3%), Hunegnaw *et al.* (2022) reported relatively higher IVDMD value (65.82%) for sole stand Mulato II grass at 90 days of harvesting age in midland agroecology. In addition, differences in maturity at harvest is also the most important factor affecting the digestibility of grasses (McDonald *et al.*, 2002) since it largely affects the leaf to stem ratio and deposition of lignin content. Besides, the IVDMD value (70.16%) for sole *D. intortum* in this study varied from the IVDMD value (61%) of *Desmodium dichotomum* in monoculture reported by Abebe (2020). The variation in IVDMD might stem from environmental conditions, differences in soil type and fertility, and management practices such as agronomic practices (Hunegnaw *et al.*, 2022).

The non-significant effect of altitude on the ME contents of forages in the current study agreed with Asmare *et al.* (2017) who showed that the ME content of desho grass was unaffected by altitude. The ME content recorded in the current study (8.8-7.91 MJ/kg DM) was higher than the minimum ME (7 MJ/Kg DM) requirement of small ruminants weighed 30 kg (Salah *et al.*, 2014). Furthermore, the decreased ME as harvesting ages increased observed in the current study is consistent with other studies (Bayble *et al.*, 2007; Muhumed, 2018).

5.5. Conclusion and Recommendations

The current result revealed that except LER, most of the morphological characteristics (PHPP, NTPP, NLPP, LLPP, LSR, NRPP for Mulato II, NB and NRNPP for *D. intortum*) were affected by the interaction effects of planting pattern, agroecologies, and harvesting ages. Accordingly, the morphological characteristics measured (PHPP, NTPP, NTPP, NLPP, LLPP, and NRPP) from intercropped Mulato II were higher at 120 days of harvesting time in lowland agroecology, whereas their respective values were lower at 90 days of harvesting time in the midland agroecology. The LSR was higher for intercropped Mulato II at 90 days of harvesting time in the lowland agroecology. Besides, PHPP, NBPP and NRNPP of *D. intortum* were also higher at 120 days of harvesting time in lowland agroecology. Further, the LER value was greater than 1 which dictates the yield advantage of the intercrop.

Besides, the interaction among planting pattern, agroecologies, and harvesting ages had a significant effect on the CP and fiber contents of Mulato II and *D. intortum*. The higher CP content was observed from intercropped Mulato II at 90 days of harvesting age in the lowland agroecology. Sole stand *D. intortum* had the highest CP content at 90 days to harvest in midland agroecology. The fiber contents (NDF and ADF) were higher for sole stand Mulato II at 120 days of harvesting age in lowland agroecology. The DMY, CPY, and IVDMD values of Mulato II and *D. intortum* were also affected by the interaction effect. The DMY was higher for intercropped Mulato II at 120 days of harvesting age in the lowland agroecology.

Harvesting at 120 days could be taken as optimum for intercropped Mulato II with *D. intortum* at lowland agroecology and it is recommended for fodder production in similar agroecological setup under rainfed condition. Research focusing the effect of spacing and seasonal variations of those forages should also be developed to exactly attest their agronomic and nutritive potentials. In addition, animal evaluation experiments based on those forages is also recommended.

CHAPTER 6: EVALUATION OF REPLACING CONCENTRATE WITH MULATO II AND GREENLEAF DESMODIUM (*Desmodium intortum*) MIXED FORAGES ON NUTRIENT AND DM INTAKE, DIGESTIBILITY AND GROWTH PERFORMANCE OF FARTA RAMS



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Evaluation of Replacing Concentrate with Mulato II and Greenleaf Desmodium (*Desmodium intortum*) Mixed Forages on Intake, Digestibility and Growth Performance of Farta Sheep

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Abstract

This study evaluated the replacement effect of concentrate with Mulato II and *Desmodium intortum* mixed forages on the intake, digestibility, and growth performance of Farta rams fed a basal diet of natural pasture hay (NPH) for a period of 90 days. Twenty-five yearling Farta rams were blocked based on their initial body weight (18 ± 1.36 kg) (mean $\pm$ SD) and randomly assigned into the five treatment diets in a completely randomized block design. The diets were: T1 (NPH *ad libitum* + concentrate only), T2 (NPH *ad libitum* + 80% concentrate + 20% Mulato II and *D. intortum*), T3 (NPH *ad libitum* + 60% concentrate + 40% Mulato II and *D. intortum*), T4 (NPH *ad libitum* + 40% concentrate + 60% Mulato II and *D. intortum*), and T5 (NPH *ad libitum* + 20% concentrate + 80% Mulato II and *D. intortum*). Mulato II and *D. intortum* were mixed at a proportion of 30 and 70%. The five treatment diets were made in such a way that the concentrate mix was progressively replaced by Mulato II and *D. intortum* forages at a proportion of 0, 20, 40, 60, and 80%. The data on feed intake, digestibility, and body

weight change was analyzed using the general linear model procedure of SAS version 9.4. The results showed that total dry matter intake, final body weight, average daily gain, and feed conversion efficiency of sheep were not affected by the replacement of concentrate with Mulato II and *D. intortum* mixed forages. In conclusion, supplementation of Mulato II and *D. intortum* forages up to 80% could replace the concentrate in the diet of Farta rams without any negative effect on the growth performance.

Keywords: Digestibility, Farta rams, growth performance, improved forages

6.1. Introduction

Ethiopia has a huge number of small ruminants estimated at 42.9 million sheep and 52.5 million goats (CSA, 2021). Though, small ruminants play a vital role in the livelihoods of many farmers, their productivity is far below their potential mainly due to poor nutrition (Nega and Melaku, 2009; Etalema and Abera, 2018; Castro-Montoya and Albarrán-Portillo, 2023; Gninkplékpo *et al.*, 2024). Shortage of feed in terms of both quantity and quality is also the major contributing factor to the low productivity of animals elsewhere in the country (Welay *et al.*, 2018; Seid *et al.*, 2021; Duguma and Janssens, 2021). The major feed resources which form the prominent part of the diet for animals especially natural pasture, crop residues and crop aftermaths are low in energy, crude protein, and digestibility (Shapiro *et al.*, 2017; Bayissa *et al.*, 2022). The poor digestibility of those low quality feeds cannot provide all the nutrient requirements of rumen microorganisms (Van Soest, 1994). Besides, the contribution of natural pasture as feed for livestock is even getting diminished due to the conversion of grazing lands into arable lands mainly because of high population pressure (Mekasha *et al.*, 2014; Gebresamuel *et al.*, 2022). The exclusively reliance on utilization of these high roughage diets for livestock resulted in low productivity (Korir *et al.*, 2022). Consequently, exploring alternative feed ingredients is compulsory to efficiently utilize bulky and fibrous crop residues as they cannot improve productivity when they are fed alone (Tolera and Sundstol, 2000; Tulu *et al.*, 2024). Conventional concentrate feeds such as cereal grains and agroindustrial byproducts (oilseed cakes and cereal brans) are good sources of supplementation (Dida *et al.*, 2024). But, it is obvious that many smallholder

farmers in most parts of the country cannot afford and/ or access conventional concentrate feeds for their animals because of scarcity and expensive costs (Beigh *et al.*, 2021). Thus, supplementation with cultivated forages such as grass and legume mixture, that can be grown locally, could offer an alternative to concentrates and appears to be a more feasible way to improve the existing low productivity of sheep. Mulato II (Mulato II) and *D. intortum* are among the potential forages that could be used as an essential alternative to enhance the performance of sheep. According to Farghaly *et al.* (2022), forages could produce cheaper rations thereby filling the gap of energy and protein in the diets of animals.

According to Argel *et al.* (2007), Mulato II grass is highly valued for its performance under acidic and well drained soils which could be easily established through its seeds and vegetative propagation. The deep root system of forage crops enables to resist drought stress (Ye *et al.*, 2018). The grass is also highly nutritious and capable of meeting the nutrient requirements of animals (Zampaligré *et al.*, 2022). Similarly, *D. intortum* also resists drought. Due to its higher CP content, it has been used as a supplement in tropical cattle production and contributes to a better utilization of low quality feeds (Tolera and Sundstol, 2000; Korir *et al.*, 2022). Furthermore, both Mulato II and *D. intortum* are used in push-pull technology predominantly to control crop pests and weeds in many parts of Ethiopia.

With the exception of limited studies in supplementing Mulato II and *D. intortum* forages separately for animal evaluation experiments, there is a lack of data describing the use of Mulato II and *D. intortum* mixed forage as a supplement in sheep ration. In previous findings, Mulato II grass supplementation was evaluated on the performance of various breeds of sheep (Adnew *et al.*, 2021; Ahmed *et al.*, 2023). The supplementation value of *D. intortum* hay for sheep was also reported by Tolera and Sundstol (2000). As supplementation of *D. intortum* hay increased, the body weight gain showed a significant increase ($p < 0.05$) and considering DM intake and digestibility, 300 g of desmodium hay appears to be an optimum level of supplementation.

Hence, the present study was conducted to evaluate whether Mulato II and *D. intortum* mixed forages could be a potential alternative supplement to concentrate feeds on feed intake, digestibility, and body weight change of Farta rams fed natural pasture hay as a basal diet.

6.2. Materials and Methods

6.2.1. Description of the study area

This feeding trial was conducted in sheep and goat farm at Zenzelma Campus, Bahir Dar University which lies between 11°37'North latitude and 37°28'East longitude. The altitude of the area is 1911 m.a.s.l. The annual average temperature was 29 °C. The annual rainfall of the area was 1428-1521 mm. The main rainy season spells from June to September.

6.2.2. Experimental animals and their management

For this study, twenty-five yearling Farta rams with an average initial body weight of 18 ± 1.36 kg (mean $\pm$ SD) were purchased from the local market of Farta district by Bahir Dar University. The age of each sheep was estimated based on dentition and oral history provided by the owners. After arrival, they were housed in separate concrete house equipped with adequate floor space, feed and water troughs. Before the commencement of the experiment, sheep were placed on individual pen for 15 days of acclimatization period. This was to enable experimental animals get accustomed to the new environment and acclimatize to the test feeds. The house was disinfected and cleaned daily. All sheep were identified with ear tag, vaccinated, and dewormed. Furthermore, they were closely observed and checked for incidence and sign of any ill health and disorders throughout the experimental period.

6.2.3. Experimental feed preparation

With the exception of Mulato II and *D. intortum* forages, the remaining feed ingredients were obtained from Bahir Dar University livestock feed store. Mulato II and *D. intortum* forages were produced at the research site of Bahir Dar University, Ambomesik *kebele*. Fertilizer was applied to Mulato II for establishment. They were also

properly managed through weeding at time of weed infestation. At four months of age, the forages were harvested by hand using sickle. The forages were dried under shade to prepare hay. In addition, *D. intortum* was spread over a canvas to protect leaf loss while drying (Tolera and Sandstol, 2000). At the experimental site, those forage species including the natural pasture hay were chopped through a chopper for appropriate feeding. The concentrate was composed of noug seed cake, wheat bran, and ground maize grain. The maize grain was ground in the livestock feed processing unit at Zenzelma campus, Bahir Dar University.

6.2.4. Experimental design and treatments

At the end of the preliminary period, animals were weighed after overnight fasting for two consecutive days and the average body weight was used to categorize them into blocks. Then, the sheep within each block were assigned randomly to one of the five treatment diets using Randomized Complete Block Design (RCBD). Basal (natural pasture hay) and supplemental diets were offered separately. The supplemental diets were offered twice a day, at 8:00 AM and 16:00 PM on equal proportion basis. The sheep were offered with the basal diet *ad libitum* with the amount fed adjusted weekly to allow a 20% refusal. Clean water was provided as *ad libitum*. All sheep also had access to salt.

Five dietary treatments were used for this sheep evaluation experiment. Based on the previous recommendation for yearling Farta rams, the supplement diet was offered at 400 g/h/day (Asmare *et al.*, 2010). The concentrate was replaced progressively by Mulato II and *D. intortum* forages at a proportion of 0, 20, 40, 60 and 80% on DM basis. Mulato II and *D. intortum* forages was mixed at a proportion of 30:70%. The treatment setup of the experiment containing natural pasture hay as a basal diet for this study is presented in Table 6.1.

Table 6.1. Proportion of feed ingredients and nutrient concentration of treatment diets (% DM basis, unless specified)

Feed ingredients	Treatment diets				
	T1	T2	T3	T4	T5
Natural pasture hay (NPH)	<i>Ad lib</i>	<i>Ad lib</i>	<i>Ad lib</i>	<i>Ad lib</i>	<i>Ad lib</i>
Physical proportion of feed ingredients					
Noug seed cake (NSC)	20.8	17.88	14.25	12	6.5
Wheat bran (WB)	49	41.34	30	20	9.5
Ground maize grain (GMG)	29.2	19.78	14.75	7	3
Mulato II	0	6	12	18	24
<i>D. intortum</i>	0	14	28	42	56
Common salt	1	1	1	1	1
Total	100	100	100	100	100
Nutrient concentration					
CP	17.2	16.8	16.0	15.6	15
ME, MJ/kg DM	8.9	8.5	8.1	7.7	7.4

T1= NPH *ad libitum*+ concentrate only; T2= NPH *ad libitum*+ 80% concentrate+ 20% Mulato II and *D. intortum*; T3= NPH *ad libitum*+ 60% concentrate+ 40% Mulato II and *D. intortum*; T4= NPH *ad libitum*+ 40% concentrate+ 60% Mulato II and *D. intortum*; T5= NPH *ad libitum*+ 20% concentrate+ 80% Mulato II and *D. intortum*

6.2.5. Feeding trial

The feeding trial lasted 90 days excluding the 15 days of acclimatization period. The feed offered and refusals were recorded daily for each sheep throughout the study period. The feed intake was determined by subtracting the hay refusal from the daily feed offer. Subsamples of feed offered and refusals were collected on daily basis through a plastic bag from each treatment diets in the morning prior to providing the daily feed offer. Then, the subsamples were pulled for each treatment diets and prepared for chemical analysis. Initial body weight was taken at the start of the actual feeding experiment. Body weight was measured every 15 days after overnight fasting in the morning before feed offer. The final body weight measurement was taken at the end of the feeding experiment. The daily body weight gain was computed as the difference between final and initial body weight divided by number of feeding days. Feed conversion efficiency (FCE) was calculated by dividing the average daily weight gain to average daily feed intake in gram.

$$\text{That is, FCE} = \frac{\text{ADG(g)}}{\text{ADFI (g)}}$$

Where, ADG= Average daily weight gain and ADFI= Average daily feed intake

6.2.6. Digestibility trial

The digestibility trial was conducted using all experimental animals at the end of the feeding trial. The experimental animals were allowed to adapt harnessing of faecal collection bags for four days before the actual data collection. The faecal sample was collected separately using fecal collection bag fitted to each experimental sheep for 7 consecutive days. Before any new feed offer, feed refusals and faeces were collected and weighed every day in the morning. The daily representative faecal samples collected from each experimental animal were kept and frozen at -10 °C in refrigerator. At the end of the digestibility trial, a composite fecal sample of 20% was taken after thorough mixing and pooled over the collection period for each animal. The collected fecal sample for digestibility determination was partially dried at 65 °C for 72 hours. Then, the oven dried sub-samples were ground to pass through a 1 mm sieve size and stored in an airtight polyethylene bag pending chemical analysis.

The apparent digestibility percentage was computed using the following formula:

$$\text{Apparent digestibility (\%)} = \frac{\text{Nutrient in feed} - \text{Nutrient in faeces}}{\text{Nutrient in feed}} * 100$$

6.2.7. Chemical analysis

Samples of feeds, refusals and faeces were kept in an oven and dried at 65 °C for 48 hours. Then, the dried samples were ground using Willey mill to pass through 1 mm sieve size and were kept packed in a plastic bag pending further analysis. DM and Ash contents of forage samples were determined following the procedure of AOAC (2005). The dry matter content of partially dried feed samples was determined by drying the sample in forced draft oven at 105 °C overnight. Ash was determined by complete burning or igniting feed samples in a muffle furnace at 550 °C for three hours. Organic matter (OM) percentage was calculated as 100 minus ash percentage. Kjeldhal procedure (AOAC, 2005) was used to determine total nitrogen (N) and crude protein (CP) was calculated as N*6.25. Acid detergent fiber (ADF), neutral detergent fiber (NDF) and acid detergent lignin (ADL) were analyzed using Van Soest *et al.* (1991).

6.2.8. Statistical analysis

The feeding and digestion experiment data were subjected to analysis of variance (ANOVA) using the general linear model (GLM) procedure of SAS version 9.4. The least significant difference (LSD) test was used to separate the treatment mean at 5% significant level. Additionally, correlation analysis was performed for DM, nutrient intakes, digestibility, and body weight gain. The model statement for feeding and digestion trial was:

$$Y_{ij} = \mu + T_i + B_j + \epsilon_{ijk}$$

Where Y_{ijk} = response variable

μ = overall mean

T_i = treatment effect

B_j = block effect

ϵ_{ijk} = residual error

6.3. Results

6.3.1. Chemical composition of experimental feed ingredients and treatments

The chemical composition of feed ingredients, treatments, and hay refusals for this experiment is presented in Table 6.2. The CP value of the natural pasture hay was 6.38% and its NDF content was 71.32%. Whereas, noug seed cake had the higher CP value (31.15%) than the remaining feed ingredients. As expected, the hay refusals had lower crude protein percentage and higher NDF and ADF contents than the corresponding treatment diets.

Table 6.2. Chemical composition of experimental feed ingredients and treatments (% DM basis unless specified)

	Chemical composition					
	DM	Ash	CP	NDF	ADF	ADL
Feed ingredients						
NPH	91.52	9.36	6.38	71.32	47.6	17.84
NSC	89.58	9.91	31.15	43.35	20.96	6.77
WB	91.76	12	16	51.88	16.89	4.56
GMG	88.9	8.8	10	41.54	21.87	4.17
MII	92.13	12.68	10.5	64.54	13.92	8.71
DI	89.39	9.67	14.49	55.1	36.45	9.98

Table 6.2. Chemical composition of experimental feed ingredients and treatments (% DM basis unless specified) (Continued)

Treatment feeds						
T1	90.25	7.5	13.45	43.2	32.8	10.6
T2	90.47	7.73	12.66	46.5	33.4	11.3
T3	91.52	8.86	11.46	46.7	35.2	11.7
T4	91.68	9.41	10.55	47.3	36	12.9
T5	91.76	9.83	9.87	49.5	38.26	15.2
Hay refusals						
T1	91.62	8.71	3.81	69.94	41.1	16
T2	92.4	9.78	3.67	71.46	45	15.34
T3	92.1	10.11	3.56	71.98	51	13.5
T4	92	9.63	3.64	70.45	49.8	11.2
T5	90.91	10.56	3.55	72.57	46.25	14.51

DM= dry matter; OM= organic matter; CP= crude protein; NDF= Neutral detergent fiber; ADF= acid detergent fiber; ADL= Acid detergent lignin; NPH= natural pasture hay; NSC= Noug seed cake; WB= wheat bran; GMG= ground maize grain; MII= Mulato II; DI= *Desmodium intortum*; T1= NPH *ad libitum*+ concentrate only; T2= NPH *ad libitum*+ 80% concentrate+ 20% Mulato II and *D. intortum*; T3= NPH *ad libitum*+ 60% concentrate+ 40% Mulato II and *D. intortum*; T4= NPH *ad libitum*+ 40% concentrate+ 60% Mulato II and *D. intortum*; T5= NPH *ad libitum*+ 20% concentrate+ 80% Mulato II and *D. intortum*

6.3.2. Feed and nutrient intake

Table 6.3 shows the daily DM and nutrient intake of Farta rams fed natural pasture hay *ad libitum* and supplemented with Mulato II and *D. intortum* mixed forages substituting concentrate. The basal hay intake, TDMI, TDMI (%BW) and TDMI expressed as gram per metabolic body weight were not affected by the different treatment diets ($P>0.05$). The sheep consumed all the supplements at T1, T2, and T3 groups. Besides, OMI, CPI, NDFI, ADFI and ADLI of sheep varied among treatments ($P<0.05$). The total CPI of sheep of T1 (102.9 g/day), T2 (102.6 g/day), and T3 (101.96 g/day) was statistically similar and greater than T4 (101.3 g/day) and T5 (100.97 g/day). The highest NDFI, ADFI, and ADLI were observed for sheep in T5.

Table 6.3. Mean daily feed and nutrient intake of Farta rams fed natural pasture hay supplemented with Mulato II and *D. intortum* mixed forages substituting concentrate mix at different levels

Intake (g/day DM)	Treatments					SEM	P value
	T1	T2	T3	T4	T5		
NPH	383.64	382.48	381.76	381.23	379.96	1.296	0.91
Supplement	396 ^a	396 ^a	396 ^a	390.64 ^b	391.38 ^b	0.625	0.0002
TDMI	779.64	778.48	777.76	771.87	771.34	1.464	0.108
TDMI (%BW)	3.1	3.2	3.2	3.22	3.4	0.034	0.13
TDMI (g/kgW ^{0.75} /day)	69.7	71.1	71.2	71.2	74.2	0.56	0.169
Total nutrient intake							
OM	695.44 ^a	693.63 ^a	695.32 ^a	684.65 ^b	682.64 ^b	1.603	0.002
CP	102.9 ^a	102.6 ^a	101.96 ^{ab}	101.3 ^b	100.97 ^b	0.227	0.004
NDF	336.81 ^c	361.68 ^b	363.21 ^b	365.1 ^b	381.81 ^a	3.003	<0.0001
ADF	255.72 ^e	260.01 ^d	273.77 ^c	277.87 ^b	295.12 ^a	2.892	<0.0001
ADL	82.64 ^e	87.97 ^d	91 ^c	99.57 ^b	117.24 ^a	2.474	<0.0001

^{a-c}Treatment means with different superscript letters in a row are significantly different (P<0.05).

TDMI= total dry matter intake; OM= organic matter; CP= crude protein; NDF= Neutral detergent fiber; ADF= acid detergent fiber; ADL= Acid detergent lignin; NPH= natural pasture hay; T1= NPH *ad libitum*+ concentrate only; T2= NPH *ad libitum*+ 80% concentrate+ 20% Mulato II and *D. intortum*; T3= NPH *ad libitum*+ 60% concentrate+ 40% Mulato II and *D. intortum*; T4= NPH *ad libitum*+ 40% concentrate+ 60% Mulato II and *D. intortum*; T5= NPH *ad libitum*+ 20% concentrate+ 80% Mulato II and *D. intortum*

6.3.3. Apparent digestibility of dry matter and nutrients

The apparent digestibility of DM and nutrients by sheep fed natural pasture hay basal diet and supplemented with Mulato II and *D. intortum* mixed forages substituting concentrate are shown in Table 6.4. Significant differences were not observed among treatments (P>0.05) in terms of the digestibility of DM, OM, CP, NDF and ADF.

Table 6.4. Digestibility of DM and nutrients in Farta rams fed natural pasture hay supplemented with Mulato II and *D.intortum* forages replacing concentrate mix

Digestibility (%)	Treatments					SEM	P value
	T1	T2	T3	T4	T5		
DM	70.74	67.82	66.43	65.98	64.42	0.802	0.173
OM	72.82	72.03	70.5	69.34	68.15	0.646	0.153
CP	67.18	66.65	65.9	65.3	64.33	0.334	0.08
NDF	67.55	67.26	66.66	66.06	65.69	0.239	0.061
ADF	50.12	49.84	49.42	49.3	48.54	0.258	0.4

DM= dry matter; OM= organic matter; CP= crude protein; NDF= Neutral detergent fiber; ADF= acid detergent fiber; T1= NPH *ad libitum*+ concentrate only; T2= NPH *ad libitum*+ 80% concentrate+ 20% Mulato II and *D. intortum*; T3= NPH *ad libitum*+ 60% concentrate+ 40% Mulato II and *D. intortum*; T4= NPH *ad libitum*+ 40% concentrate+ 60% Mulato II and *D. intortum*; T5= NPH *ad libitum*+ 20% concentrate+ 80% Mulato II and *D. intortum*

6.3.4. Body weight measurements and feed conversion efficiency

The body weight measurements and feed conversion efficiency of Farta rams fed natural pasture hay and supplemented with Mulato II and *D. intortum* mixed forages replacing concentrate are presented in Table 6.5. The FBW, ADG, and FCE of sheep had no variation ($P>0.05$) across the five treatment diets.

Table 6.5. Body weight measurements and feed conversion efficiency in Farta rams fed natural pasture hay supplemented with Mulato II and *D. intortum* mixed forages substituting concentrate

Parameters	Treatments					SEM	P value
	T1	T2	T3	T4	T5		
Initial BW (kg)	18.4	17.9	18.1	18.2	18.1	0.272	0.962
Final BW (kg)	25	24.4	24.3	24	22.7	0.254	0.058
ADG (g d ⁻¹)	73.78	71.33	68.44	64.44	51.78	2.68	0.087
FCE	0.095	0.092	0.088	0.084	0.067	0.003	0.098

BW= body weight; ADG= average daily gain; FCE= feed conversion efficiency; T1= NPH *ad libitum*+ concentrate only; T2= NPH *ad libitum*+ 80% concentrate+ 20% Mulato II and *D. intortum*; T3= NPH *ad libitum*+ 60% concentrate+ 40% Mulato II and *D. intortum*; T4= NPH *ad libitum*+ 40% concentrate+ 60% Mulato II and *D. intortum*; T5= NPH *ad libitum*+ 20% concentrate+ 80% Mulato II and *D. intortum*

6.3.5. Correlation between DM, nutrient intake, digestibility, and body weight gain

The correlation between DM and nutrient intake, digestibility, and weight gain of Farta rams are presented in Table 6.6. The DMI and OMI were positively correlated ($P<0.05$) with CPI. The OMI was also positively correlated ($P<0.05$) with DMD, OMD, NDFD, ADFD, and ADG, but negatively correlated ($P<0.05$) with NDFI and ADFI. In addition, the CPI was positively correlated ($P<0.05$) with DMD, OMD, CPD, NDFD, ADFD, and ADG, but it was negatively correlated ($P<0.05$) with NDFI and ADFI. Similarly, the NDFI was positively correlated ($P<0.05$) with ADFI while it was negatively correlated ($P<0.05$) with DMD, OMD, CPD, NDFD, ADFD, and ADG. Furthermore, the DMD and CPD were positively correlated ($P<0.05$) with ADFD and ADG. However, the fiber digestibility (NDFD and ADFD) did not show any significant correlation ($P>0.05$) with ADG.

Table 6.6. The correlation between DM, nutrient intake, digestibility, and weight gain of Farta rams

	DMI	OMI	CPI	NDFI	ADFI	DMD	OMD	CPD	NDFD	ADFD	ADG
DMI	1	0.4*	0.6**	0.17	0.12	0.21	0.1	-0.03	0.21	0.21	0.13
OMI		1	0.95***	-0.37	-0.47*	0.44*	0.42*	0.37	0.56**	0.43*	0.51**
CPI			1	-0.42*	-0.52**	0.49**	0.45*	0.39*	0.59**	0.46*	0.51**
NDFI				1	0.89***	-0.48*	-0.44*	-0.55**	-0.46*	-0.33	-0.46*
ADFI					1	-0.46*	-0.5**	-0.6***	-0.54**	-0.38	-0.53**
DMD						1	0.24	0.17	0.23	0.47*	0.46*
OMD							1	0.3	0.78***	0.18	0.39*
CPD								1	0.38	0.58**	0.51**
NDFD									1	0.38	0.17
ADFD										1	0.27
ADG											1

*= $P<0.5$; **= $P<0.01$; ***= $P<0.001$; DMI=dry matter intake; OMI= organic matter intake; NDFI= neutral detergent fiber intake; ADFI= acid detergent fiber intake; DMD= dry matter digestibility; OMD= organic matter digestibility; CPD= crude protein digestibility; NDFD=neutral detergent fiber digestibility; ADFD= acid detergent fiber digestibility; ADG= average daily gain

6.4. Discussion

6.4.1. Chemical composition of experimental feeds and treatments

The low CP and high NDF, ADF, and ADL values of the natural pasture hay observed in this experiment, is an indicator of the typical features of most low quality roughages available for livestock in Sub-Saharan Africa (Tolera and Sundstol, 2000). This suggests sole natural pasture hay could not support even the maintenance requirement of sheep (Mekuriaw and Asmare, 2018; Ayele and Abebe, 2023). According to Van Soest (1994), feeds with low CP contents (3-7%) impair the rumen function. Thus, supplementation is very crucial for animals striving with sole natural pasture hay-based diet (Tesfay and Tesfay, 2013).

In line with the current result (31.15%), Nega and Melaku (2009) reported a CP value of 31.26% for noug seed cake. On the other hand, Tesfay and Tesfay (2013) observed higher CP content (35.3%) for noug seed cake. The variation in CP content could be attributed to the differences in the efficiency and methods used to extract oil from noug seed. For example, expeller process with high temperatures and pressures may denature the protein and reduce its digestibility by lowering of its nutritive value. In solvent extraction process, comparatively low temperature with no pressing is used which does not alter the protein value of the meals (McDonald *et al.*, 2010). Further, the variation in CP content of wheat bran may arise from the effect of processing in milling industries and the quality of the grain used for milling (McDonald *et al.*, 2002).

These days, the use of improved forages particularly grasses and legumes as a supplement to low quality feeds has been taken as a means of averting feed related crises in East Africa. In the current study, the CP content (10.5%) of Mulato II grass hay was slightly lower than that of Adnew *et al.* (2021) who documented a CP value of (12.1%) for the same cultivar. Mutimura *et al.* (2018) also reported higher CP value (15.79%) for *Brachiaria Brizantha* cv. Piata grass but lower NDF (32.93%) and ADF (32.38%) contents compared to the current study (NDF: 64.54% and ADF: 13.92%). The disparity in CP, NDF, and ADF concentration between these studies could be associated with growing environment, stage of harvest, season, management and cultivars. Moreover, the

CP (14.49%), NDF (55.1%), and ADF (36.45%) values of *D. intortum* were relatively higher than the finding of Tolera and Sundstol (2000) who found (13.8, 53.3, and 35.1%) for CP, NDF, and ADF contents of the same cultivar, respectively. Further, Korir *et al.* (2022) reported a lower CP (10.7%), but higher NDF (56.6%) and ADF (42.2%) contents for the same cultivar compared to the current result. The discrepancy in nutritive value of *D. intortum* might be attributed to differences in stage of maturity at harvest, soil condition, proportion of leaves to stems and post-harvest handling. The CP contents of Mulato II (10.5%) and *D. intortum* (14.49%) recorded in this experiment exceeded the CP (7%) requirement for maintenance, suggesting their potential to supplement animals striving with low quality roughages such as natural pasture hay. On top of this, the hay refusals had lower CP and higher fiber components (NDF, ADF, AND ADL contents) than the offered treatment feeds which most likely be due to the selection of more palatable parts of the hay. Indeed, sheep and goats are selective in their feeding habit (Dias-Silva and Abdalla-Filho., 2020). They select the most nutritious part of a particular feed. Consequently, more lignified constituents of the hay parts were unselected which mainly contributed to the low CP coupled with high fiber components of the hay refusals in the current study.

6.4.2. Daily feed and nutrient intake of Farta rams

According to McDonald *et al.* (2010), feed intake and the quality of the diet are strongly interrelated. Feed intake is mainly influenced by feed and animal related factors. Several studies showed that fiber components (NDF, ADF, and ADL) in roughages cause physical constraints on intake (Van Soest, 1994; Betsha and Melaku, 2009; Atsbha *et al.*, 2021; Mutimura *et al.*, 2018).

Although the sheep had statistically similar DMI of the natural pasture hay across the treatments, there was a tendency to slightly decline in TDMI of basal diet from T1 to T5 as the level of Mulato II and *D. intortum* forages increased in the supplement. The bulkiness of the forage hay might contribute to the gut fill thereby depressing basal diet intake. In contrast to the current finding (383.64-379.96 g/day), the natural pasture hay (basal diet) was observed to increase progressively (327-453 g/day) when forage legume

hay increased in the supplement (Baloyi *et al.*, 2008). The variation in basal diet intake in these studies presumably due to inherent differences in the type, level, and quality of supplements used in those feeding experiments. The sheep consumed all the supplements offered at T1, T2, and T3 treatment groups probably because of no hindrance as a result of high fiber inclusion. The TDMI (771.34-779.64 g/day) found in this study were within the figure (732-851 g/day) reported by Adnew *et al.* (2021) for growing Farta lambs fed Mulato II and natural pasture hays in various proportions as a basal diet supplemented with a local concentrate mixture.

The TDMI as percent of body weight obtained (3.1-3.4%) in this study was found within the DMI range (2–6%) recommended for ruminants by ARC (1980). Furthermore, the metabolic body weight ($69.7\text{--}74.2 \text{ g/kg W}^{0.75}$ per day) in this experiment was lower than the figure ($81.69\text{--}75.23 \text{ g/kg W}^{0.75}$ per day) reported by Tulu *et al.* (2018) for Horro sheep fed *Lablab purpureus* cultivars and concentrate mixture. The CP intake (100.97-102.9 g/day) recorded in the present study was higher than the result (28.4-66.8 g/day) for Farta lamb reported by Adinew *et al.* (2021), but lower than the range (71.1-112 g/day) for Adilo rams supplemented oat-vetch mixed forage (Mengistu *et al.*, 2021b). The current finding also disagreed with that of Shitaneh *et al.* (2021) who reported relatively higher CPI (100.54-126.97 g/day) for Gumuz sheep supplemented with cowpea substituting noug seed cake. Such a discrepancy in TDMI and CPI could probably be due to the variation in the composition of feeds, quality, and levels of supplementation. The likely reason behind the highest NDFI (381.81 g/day), ADFI (295.12 g/day), and ADLI (117.24 g/day) for sheep assigned in T5 could be due to the concentration of high cell wall components as the level of forage supplements increased. In due regard, McDonald *et al.* (2002) stated that quality of feed, rate of digestion, and voluntary feed intake are positively correlated in ruminant nutrition.

6.4.3. Apparent digestibility of dry matter and nutrients

The digestibility of feed and its quality are positively associated. Feed having a DM digestibility of less than 55% is considered to be poor quality, but feeds exceeding 65% is high quality (David, 2007). As a result, the DM digestibility of treatment feeds

(64.42-70.74%) observed in this experiment could suggest its potential to improve the body weight of sheep owing to its good quality. The nonsignificant variation in apparent digestibility coefficients of nutrients in this study could suggest the potential of forage supplements to replace concentrates in the diet of sheep. The provision of high quality feeds enabled ruminal microbes to get nutrients that enhance the total digestibility of dietary nutrients (McDonald *et al.*, 2010).

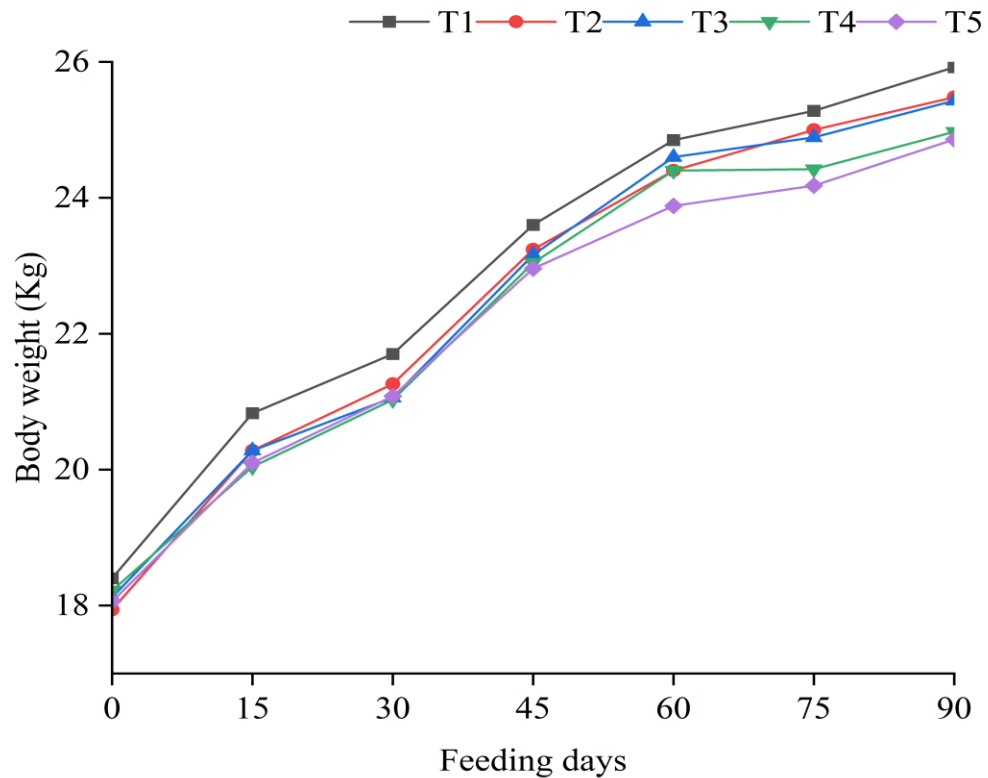
And yet, values for the digestibility of DM (64.42-70.74%) in this study was found to be within the range (62-79%) for Farta ram lamb fed natural pasture and Mulato II grass hay as a basal diet supplemented with concentrate mixture (Adinew *et al.*, 2021). Contrary to our work, lower mean DM digestibility range (29.5-67.2%) was indicated by Tolera and Sundstol (2000) for local sheep supplemented with graded levels of *D. intortum* hay. According to McDonald *et al.* (2010), protein rich feeds promote high microbial population which enhance rumen fermentation while, feeds with lower CP content could affect the rumen fermentation which in turn depress digestibility.

6.4.4. Body weight gain and feed conversion efficiency

The nonsignificant effect observed as a result of the replacement of concentrate with Mulato II and *D. intortum* mixed forages on average daily gain (ADG) of Farta rams among the five treatment diets might be due to similar feed intake and digestibility across those treatment diets. This could also suggest the potential of Mulato II and *D. intortum* mixed forages to replace the concentrate. Moreover, the positive growth performance of Farta rams across the experimental periods is shown in Figure 6.1. From this finding, it observed that, all the five treatment diets positively enhanced the growth performance of the sheep which implies the comparative nutritional values of the forage supplements (Mulato II and *D. intortum*) relative to the offered concentrate feeds.

The ADG in the current study (51.78-73.78 g/day) were within the figure (39.6-82.7g/day) reported by Adnew *et al.* (2021) for Farta rams fed natural pasture hay and Mulato II hays alone and in various combinations along with a concentrate mixture. The ADG could be affected due to the variation in feed composition, quality, and level of inclusion in the total ration and genetic potential of the breed (Douglas *et al.*, 2015). On top of this, positive relationship between FCE and ADG was reported in earlier studies

(Estifanos and Melaku, 2009). Due to similar intake and ADG across the five treatment diets, similar FCE was observed in the current finding for those experimental diets.



T1= NPH *ad libitum*+ concentrate only; T2= NPH *ad libitum*+ 80% concentrate+ 20% Mulato II and *D. intortum*; T3= NPH *ad libitum*+ 60% concentrate+ 40% Mulato II and *D. intortum*; T4= NPH *ad libitum*+ 40% concentrate+ 60% Mulato II and *D. intortum*; T5= NPH *ad libitum*+ 20% concentrate+ 80% Mulato II and *D. intortum*

Figure 6.1. Trends in body weight changes for Farta rams fed natural pasture hay basal diet and supplemented with Mulato II and *D. intortum* mixed forages substituting concentrate

6.4.5. Correlation between DM and nutrient intake, digestibility, and body weight gain

The presence of a significant positive correlation between DMI and CPI in our study could suggest an increase in DMI is a result of enhanced CPI in sheep. In agreement with our study, Shitaneh *et al.* (2021) reported a significant positive correlation between DMI and CPI for Gumuz sheep supplemented with *Vigna unguiculata* hay replacing noug seed cake. The significant positive correlation between DMI and CPI was also reported in earlier study on sheep (Hailecherkos *et al.*, 2021). In

addition, the positive correlation between CPI and DMD, OMD, CPD, NDFD, ADFD, and ADG might be due to efficient provision of protein and utilization by rumen microbes thereby enhancing rumen fermentation. The positive correlation between CPI, CPD, and ADG in the current study agreed with the finding by Gemechu (2019) who observed similar association between CPI, CPD, and ADG for Horro sheep fed *Pennisetum purpureum* grass ensiled with different proportion of *Lablab purpureus*.

6.5. Conclusion and Recommendations

The current study revealed that Mulato II and *D. intortum* forages could substitute the concentrate up to 80% inclusion level for Farta rams fed natural pasture hay basal diet. Hence, this study highlights the importance of Mulato II and *D. intortum* mixed forages as an alternative quality feed compared to the inaccessible and expensive concentrates. Moreover, the effect of supplementation of those forages on fermentation characteristics, and carcass characteristics and quality should be investigated.

CHAPTER 7: REPLACEMENT VALUE OF MULATO II AND *Desmodium intortum* MIXED FORAGES TO CONCENTRATES ON BLOOD HEMATOLOGY, BIOCHEMICAL AND ENTERIC METHANE EMISSION OF FARTA RAMS

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Abstract

This study aimed at evaluating the replacement effect of concentrate with Mulato II and *Desmodium intortum* mixed forages on blood hematology and biochemical profiles and enteric methane emission of yearling rams based on natural pasture hay basal diet. Twenty-five Farta rams with an average initial body weight of 18 ± 1.36 kg (Mean $\pm$ SD) were blocked and randomly distributed into the 5 experimental diets. The five experimental diets were prepared by progressively replacing the concentrate with Mulato II and *D. intortum* mixed forages from 0 to 80%. That is, T1= NPH *ad libitum*+ concentrate only; T2= NPH *ad libitum*+ 80% concentrate +20% Mulato II and *D. intortum*; T3= NPH *ad libitum*+ 60% concentrate +40% Mulato II and *D. intortum*; T4= NPH *ad libitum*+ 40% concentrate + 60% Mulato II and *D. intortum*; T5= NPH *ad libitum*+ 20% concentrate +80% Mulato II and *D. intortum*. The data collection on blood hematology, biochemical and enteric methane emission was done using all the experimental sheep per standard procedures. Automated hematological analyzer was used for hematological tests, while, hand held laser methane gas detector was used to measure the enteric methane emission of the experimental sheep. The result showed that except red blood cell count, all the blood profiles tested were not affected by the replacement

effect of the supplemental forages ($P>0.05$). In addition, all the blood profiles tested under this study were found within the recommended ranges for the healthy sheep. Further, the sheep did not vary in terms of enteric methane emission as a result of the replacement effect ($P>0.05$). Thus, it can be concluded that the supplemental forages could be a good alternative to potentially substitute the concentrate without any negative effect on both animal health and the environment.

Keywords: Blood profiles, Concentrates, Forages, Methane emission, Sheep

7.1. Introduction

The vast majority of rural populations worldwide depend on the livestock sector for their livelihoods (FAO, 2018). Small ruminants play a pivotal role in the livelihood of smallholder farmers. Globally, successful and sustainable livestock production are an interplay of several factors such as climate change, nutrition, reproduction and breeding, animal health and welfare (Lamy *et al.*, 2012). In particular, feed is the major driver of the sector which accounts for up to 70% of the total cost of livestock production (Makkar, 2018; Begna and Masho, 2024). The predominant feed resources available for livestock in Ethiopia are natural pasture (54.54%) and crop residues (31.13%) (CSA, 2021). Nonetheless, the land available for natural pasture is drastically declining due to its conversion into cropland arising from the alarmingly increased human population (Atsbha *et al.*, 2015; Wegi *et al.*, 2021). Yet, natural pasture and crop residues are characterized by their poor nutritive value coupled with inadequate quantity. Besides, climate change is among the pressing problems that could bring significant impact on forage productivity (Garnett, 2009; Bogale and Erena, 2022). Consequently, the production and productivity of farm animals at stake are highly constrained. Further, the low quality feed resources are not only limited to affect the production and productivity of livestock but also may have an immense impact on animal health and the environment (Lamy *et al.*, 2012). Concentrates such as cereals, legume grains, and agro-industrial byproducts are high quality feed ingredients for animals. However, use of concentrates as animal feed is yet challenging for smallholder farmers especially in developing countries due to scarcity and high cost. Human competition for the consumption of grains also exacerbates the existing problem.

Nowadays, alternative feed ingredients such as cultivated improved forages have got much attention in animal nutrition to wrestle the livestock feed gap. In this regard, grass and legume forage mixtures play utmost role to achieve successful and sustainable livestock production by providing essential nutrients (Notenbaert *et al.*, 2024) such as protein and energy. Mulato II and *D. intortum* are among the candidate forage species. These forage species are characterized by being cheap, locally cultivated, resistant to drought, and have high biomass and nutritive value. They are also highly valued in push-pull technology (PPT) primarily as a crop pest management system in which Mulato II grass as a trap plant while *D. intortum* as repellent. In spite of the fact that there is very limited study about the supplementary values of each of the forage species in an on-station experiment, information is lacking with respect to mixtures of these forages and their effect on animal health and the environment since ruminant animals are the sources of greenhouse gas emission.

Methane is a fermentation byproduct primarily in the rumen and small amount in the hind gut of ruminants because of carbohydrate fermentation by methanogenic archaea. The production of methane results in a loss of up to 12% of the gross energy intake which otherwise be useful to improve animal performance. At the same time, methane is a major source of greenhouse gas emission (Gerber *et al.*, 2013; Gaviria-Uribe *et al.*, 2020) which contributes to global warming (Lanzoni *et al.*, 2022). Methane emissions from enteric fermentation in cattle represent approximately 40% of the total emissions from agriculture (Gaviria-Uribe *et al.*, 2020). According to Soren *et al.* (2015), the quality of feeds consumed by ruminants determine the amount of enteric methane emission released into the environment. Consequently, when poor quality of feed is fed to the ruminants, there will be higher CH₄ production per unit of product than better fed animals.

Besides, studies are available on the use of Mulato II and *D. intortum* forages as a supplement for animals elsewhere. In a recent study, Ahmed *et al.* (2023) also observed the potential of Mulato II grass to enhance the growth performance of Yankasa rams in Nigeria. In Ethiopia, Adnew *et al.* (2021) evaluated the potential of this grass in a sheep

evaluation experiment and observed its potential in improving the growth performance of Farta rams. On top of this, *D. intortum* forage legume has been used as a supplement in sheep (Tolera and Sundsto, 2000). Korir *et al.* (2022) mentioned *D. intortum* forages could be a potential alternative supplement to commercial dairy concentrates in smallholder dairy production systems in east Africa.

But, these studies were limited to the growth performance of animals without further evaluating the ultimate effect of those forages on the health of animals and the environment. Thus, the effect of these forage species on the health and environment at least should be measured. This could help optimize farming practices, improve animal welfare, enhance sustainability, and minimize negative environmental impacts through greenhouse gas emissions. Therefore, the purpose of this experiment was to investigate the replacement value of Mulato II and *D.intortum* mixed forages to concentrates on the blood profiles and enteric methane emission of Farta rams.

7.2. Materials and Methods

The study area, experimental animals and management, experimental feeds and their preparation, and experimental design and treatment diets used for this study was adapted from Fekade *et al.* (2024).

7.2.1. Measurements

The measurements on blood hematology, biochemical and enteric methane emission were done after the completion of the feeding or growth experiment.

7.2.1.1. Blood sample collection and analysis

Blood samples were collected at the end of the growth experiment from all sheep using blood collection needle. Blood samples were collected in a purple top 5 ml vacuum tubes containing 10% anticoagulant ethylene diamine tetraacetic (EDTA). The blood samples were taken from the jugular vein in the morning before the daily feed offer. All the blood samples were then taken immediately to Tibebe Ghion Specialized Hospital Laboratory, Bahir Dar University. The blood hematological tests were analyzed by automated hematology analyzer (BC-5800 automated hematological analyzer, Mindray,

China). The hematological parameters tested were packed cell volume (PCV), hemoglobin (Hgb), total white blood cells (WBC), red blood cells (RBC), platelets, mean corpuscular volume (MCV), mean corpuscular hemoglobin concentration (MCHC).

The blood samples for the serum biochemical analysis were also taken from all sheep in red top vacuum tubes of 7 ml with no anticoagulant. The blood samples were then taken to Biotechnology Laboratory of Bahir Dar University and centrifuged at 3000 rpm with a centrifugation force of 1620 g for 15 minutes. The serum and plasma samples were transferred into labeled grass vials and stored at a temperature of -20 °C pending analysis. The blood chemistry tests were done by an automated biochemical analyzer using a commercially available kit (Cogent TM of Span Diagnostic Ltd., Surat, Gujarat, India). The separated serum and plasma samples were then analyzed for biochemical characteristics which include glucose (Glu), blood urea nitrogen, total cholesterol, total protein, and albumin.

7.2.1.2. Measurements of enteric methane emissions

Methane gas emission was measured on sheep using handheld portable laser methane gas detector (LMD) (Tokyo Gas Engineering Co. Ltd, Tokyo, Japan). The LMD was held at a fixed distance of 1m from each sheep while measuring. The device was confirmed to be used and is a plausible technique for enteric methane emission studies in Sheep (Sorg, 2021; Bekele *et al.*, 2025). The LMD measures the methane concentration (ppm-m) between the animal and the detector using infrared spectroscopy, with a wavelength specifically set (1.7 μ m) on high selectivity to the methane absorption band. The methane emitted was recorded by pointing the green laser beam on the LMD at the muzzle of each sheep in ppm per minute (Zhao *et al.*, 2020; Sorg, 2021). The sheep were held gently to measure the methane emission without any movement disturbances (Appendix D, Figure 7.1). The methane measurements were taken three times in a day, in the morning after feeding, midday, and in the late afternoon (Roessler and Schlecht, 2021) to account for any significant effect on methane emissions because of rumen fill effects. The enteric methane gas emission was read on the LMD from each sheep for three minutes over a period of 5 consecutive days after the completion of the digestibility trial. For this particular study, we didn't convert the measured methane emission data

from ppm-m into g/day since we lack compatible device with a GasViewer app via Bluetooth to connect with the LMD device to export and sort the data. As a result, we were unable to get peaks and troughs representing the inhalation and exhalation of the respiratory cycle.

7.2.2. Statistical analysis

The blood hematology and serum biochemical characteristics and methane emission data were subjected to the general linear model (GLM) procedure of SAS version 9.4. Least significant difference (LSD) test was used to separate the treatment mean at 5% significant level. The model used for data analysis was:

$$Y_{ij} = \mu + T_i + B_j + \epsilon_{ijk}$$

Where Y_{ijk} = response variable

μ = overall mean

T_i = treatment effect

B_j = block effect

ϵ_{ijk} = residual error

7.3. Results

7.3.1. Blood hematological parameters of Farta rams

The effect of substituting concentrate feed with Mulato II and *D. intortum* mixed forages on the blood hematology characteristics of sheep is presented in Table 7.2. In this regard, sheep in T5 group had lower red blood cell (RBC) count compared to sheep fed T1, T2, and T3 ($P < 0.05$). On the other hand, white blood cell (WBC), platelet, haemoglobin (Hgb), haematocrite (HCT), mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), and mean corpuscular haemoglobin concentration (MCHC) were similar among the five treatment groups ($P > 0.05$).

Table 7.1. Haematological characteristics of Farta rams fed natural pasture hay basal diet and supplemented with different levels of concentrate replaced by Mulato II and *D. intortum* mixed forage

Parameters	RV	Treatment diets					SEM	P value
		T1	T2	T3	T4	T5		
RBC ($\times 10^6/\mu\text{L}$)	9-15 ¹	13.03 ^a	12.58 ^a	12.53 ^a	11.87 ^{ab}	11.05 ^b	0.214	0.026
WBC ($\times 10^3/\mu\text{L}$)	4-12 ¹	11.64	10.70	10.97	10.58	10.38	0.167	0.095
Plat ($\times 10^3/\mu\text{L}$)	250-750 ¹	328.65	314.75	311.02	311.6	307.62	3.492	0.449
Hgb(g/dL)	9-15 ¹	11.05	10.28	10.00	10.22	9.77	0.152	0.08
HCT (%)	27-45 ²	36.3	32.3	34.14	31.6	32.72	0.968	0.554
MCV (fL)	21.1-43.83	27.83	26.17	27.41	26.75	29.92	0.999	0.821
MCH (pg)	8-12 ⁴	8.62	8.34	8.09	8.75	8.96	0.186	0.643
MCHC (g/dL)	31-34 ²	31.06	32.52	30.03	32.81	30.66	0.967	0.856

^{a-b}Means within a row having different superscripts differ ($P < 0.05$); RV=reference values; RBC= red blood cell; WBC, white blood cell; Plat= platelet; Hgb= haemoglobin; HCT= hematocrit; MCV= mean corpuscular volume; MCH= mean corpuscular haemoglobin; MCHC= mean corpuscular haemoglobin concentration; RV= reference value; NPH= natural pasture hay; T1= NPH *ad libitum*+ concentrate only; T2= NPH *ad libitum*+ 80% concentrate +20% Mulato II and *D. intortum*; T3= NPH *ad libitum*+ 60% concentrate +40% Mulato II and *D. intortum*; T4= NPH *ad libitum*+ 40% concentrate + 60% Mulato II and *D. intortum*; T5= NPH *ad libitum*+ 20% concentrate +80% Mulato II and *D. intortum*; 1= Reece and Swenson, 2004; 2= Jain, 1993; 3= Al-Jbory and Al-Samarai, 2016; 4= Jackson and Cockcroft, (2002)

7.3.2. Biochemical parameters of Farta rams

The replacement effect of concentrate with Mulato II and *D. intortum* mixed forage on the blood biochemical parameters is shown in Table 7.3. Accordingly, blood glucose ($P = 0.092$), total protein ($P = 0.340$), albumin ($P = 0.379$), urea nitrogen ($P = 0.984$), and total cholesterol ($P = 0.285$) showed no significant variation among the experimental diets.

Table 7.2. Biochemical values of Farta rams fed natural pasture hay basal diet and supplemented with different levels of concentrate replaced by Mulato II and *D. intortum* mixed forage

Parameters	RV*	Treatment diets					SEM	P value
		T1	T2	T3	T4	T5		
Glucose (mg/dL)	50-80	55.2	54.2	54.8	53.8	53.2	0.722	0.092
Total protein (g/L)	60-79	88.4	87	86.2	84.2	83.8	0.800	0.340
Albumin (g/L)	24-30	29.6	26.8	26.2	25.6	24.8	0.723	0.379
Urea nitrogen (mg/dL)	8-20	14.8	14.6	14.2	14.4	14.0	0.400	0.984
Total cholesterol (mg/dL)	52-76	56.2	60.6	61.8	56.6	55.6	1.116	0.285

RV= reference value; NPH= natural pasture hay; T1= NPH *ad libitum*+ concentrate only; T2= NPH *ad libitum*+ 80% concentrate +20% Mulato II and *D. intortum*; T3= NPH *ad libitum*+ 60% concentrate +40% Mulato II and *D. intortum*; T4= NPH *ad libitum*+ 40% concentrate + 60% Mulato II and *D. intortum*; T5= NPH *ad libitum*+ 20% concentrate +80% Mulato II and *D. intortum*; * Kaneko *et al.* (2008)

7.3.3. Enteric methane emission of Farta rams

The replacement effect of concentrate with Mulato II and *D. intortum* mixed forage on the methane emission of Farta rams is shown in Table 7.3. There was no significant variation in enteric methane emission as a result of the different treatment diets ($P>0.05$).

Table 7.3. Enteric methane emission of Farta rams fed natural pasture hay basal diet and supplemented with different levels of concentrate replaced by Mulato II and *D. intortum* mixed forage

Measuring times	Treatment diets					P value
	T1	T2	T2	T3	T5	
Morning	35.97	30.3	32.78	36.35	37.34	0.893
Mid-day	35.12	39.38	39	34.97	34.69	
Evening	34.81	39.34	34.01	33.82	34.62	
Overall	35.3	36.34	35.26	35.05	35.55	0.992
MT*Treatment						0.620

MT= Measuring times; NPH= natural pasture hay; T1= NPH *ad libitum*+ concentrate only; T2= NPH *ad libitum*+ 80% concentrate +20% Mulato II and *D. intortum*; T3= NPH *ad libitum*+ 60% concentrate +40% Mulato II and *D. intortum*; T4= NPH *ad libitum*+ 40% concentrate + 60% Mulato II and *D. intortum*; T5= NPH *ad libitum*+ 20% concentrate +80% Mulato II and *D. intortum*

7.4. Discussion

7.4.1. Blood hematological parameters of Farta rams

Assessment of the blood haematology and biochemistry tests in animals is essential for several reasons. These tests proved valuable insights into the health,

nutritional, and metabolic status of the animals (Al-Eissa *et al.*, 2012). According to Omotoso *et al.* (2023), blood components are primarily used to assess the health condition of animals. Blood components have a direct relationship with nutrition. Feeds deficit in iron, copper, vitamin B12, or protein could cause low test results for RBC, Hgb, or HCT. In light of this, sheep grazing on poor quality pastures are susceptible to Iron deficiency. Low RBC count, Hgb, or HCT hematological parameters may indicate anemia in animals. The term anemia refers to a clinically important syndrome in small ruminants which occurs due to inadequate production of RBCs (Johns and Heller, 2021). In addition, sheep grazing on pastures with high parasite loads may also face a problem of anemia. For example, *Haemonchus contortus* is a parasitic that infects sheep which ultimately causes blood loss, and thus, result in anemia. In addition to nutrition, factors such as species, gender, and age affect the blood parameters in animals (Al-Jbory and Al-Samarai, 2016).

In the current study, the lower RBC value for T4: 11.87 and T5:11.05), than T1, T2, and T3 might be due to lower concentration of Iron in the supplements. But this result did not affect the sheep health negatively as the RBC value obtained in sheep (11.05-13.03 $\times 10^6/\mu\text{L}$) was found in the normal RBC range of 9-15 $\times 10^6/\mu\text{L}$ (Reece and Swenson, 2004). The HCT value for sheep in this study did not differ among treatments, while the values (31.6-36.3 %) were within the range (27-45%) reported for clinically healthy sheep by Jain, (1993). Moreover, MCV, MCH and MCHC are also key hematological parameters which were similar among treatments in this study, and values were within the recommended range for a healthy sheep. Fanta *et al.* (2024) reported that dietary inclusion of commercial concentrate replaced with water hyacinth had no significant effect on blood hematological parameters such as WBC, MCV, MCH, and MCHC for Doyogena sheep ($P>0.05$) comparable to the results of the current study. This could imply that replacement of the concentrate with Mulato II and *D. intortum* mixed forages is not detrimental to the health of the experimental sheep. In general, the result for most of the blood hematology parameters in this study is an indicator of the nutritional potential of Mulato II and *D. intortum* mixed forages to substitute the

concentrate feeds; diets have enough nutrients which are precursors of those blood components.

7.4.2. Biochemical parameters of Farta rams

Replacing concentrate with Mulato II and *D. intortum* mixed forage did not affect the blood biochemical parameters in sheep irrespective of the different experimental diets used in the present study. Moreover, biochemical parameters tested in this study were within the reference range of a healthy sheep (Kaneko *et al.*, 2008). This suggests that the replacement had no adverse effects on the hepatic metabolic processes or other organ functions. On top of this, the nonsignificant effect of concentrate substituted with Mulato II and *D. intortum* mixed forage on biochemical parameters could also indicate the nutrient composition of feeds and its utilization.

Previous study with similar feed types and sheep breed seems unavailable to compare with the current biochemical test results. But, there are studies on sheep fed different feed treatments which corroborates with the current study that revealed no significant difference for blood biochemical parameters. In a previous study, biochemical parameters such as glucose, total protein, albumin, and cholesterol were not affected by different levels of alternative feedstuffs for growing Awassi sheep (Awawdeh *et al.*, 2020). On the contrary, Osita *et al.* (2019) observed that inclusion of treatment diets containing yeast, grass, grass/legume mixture (50:50), and legume had significant effect on blood biochemical parameters particularly total protein and albumin for West African dwarf sheep. This might be because of variations in breed, age, growing environment, and the feed types used for the sheep during the experiments.

7.4.3. Enteric methane emission of Farta rams

Enteric methane emission using laser methane gas detector (LMD) for sheep supplemented with Mulato II and *D. intortum* mixed forages showed no significant variation among treatment diets ($P>0.05$). In line with the current study, Wang *et al.* (2019) reported nonsignificant variations in enteric methane emission of ewe lambs supplemented with concentrate meals replaced by high quality fresh ryegrass.

Higher values of methane emissions from LMD were reported compared to the current study. For instance, Bekele *et al.* (2025) found that supplementing local Menz sheep with wheat bran (WB), Niger seed cake (NG), and salt lick (control), brewery spent grain (BSG), dried leaves of *Acacia nilotica*, and *Ziziphus spina-Christi* resulted in the methane emission ranged from 17.8 to 23.3 g/day. The concentration of methane gas recorded for the sheep using LMD (35.1-36.3 ppm) in the current study was low compared to the previous finding by Chagunda *et al.* (2013) who reported methane emission value of 68.9 ppm for sheep using the same measuring device. The variations in enteric methane emissions of animals could be due to feed composition, level of feeding, and animal activities (Soren *et al.*, 2015). The same authors also further added that the microbial community within the rumen, the H₂ gas generated during anaerobic fermentation of feed materials and the balance of fermentation end products such as VFA could influence the enteric methane emission of animals. For example, inclusion of high energy feeds in animal diet such as greater proportion of concentrates reduced methane emissions due to the changes in rumen fermentation toward propionate (Bayat *et al.*, 2017).

7.5. Conclusion and Recommendations

The replacement effect of concentrate with Mulato II and *D. intortum* mixed forages had no significant effect on blood hematology and biochemical parameters tested except for red blood cells, as well as on enteric methane emissions of Farta rams. All the blood profile tests also were within the normal range for a healthy sheep.

In conclusion, the replacement of concentrate with Mulato II and *D. intortum* mixed forages up to 80% can be used for feeding Farta rams without any adverse effects on animal health and the environment. As recommendation, it is important to analyze the secondary metabolite content of the supplemental forages particularly for *D. intortum* forage legume, as these compounds significantly impact both animal health and greenhouse gas emissions. The direct influence of these forages on enteric methane emission mitigation and rumen fermentation characteristics should also be examined to better understand the connection between forage fermentation and microbial protein production and enteric methane emission.

CHAPTER 8: GENERAL DISCUSSION

The study involved a multifaceted evaluation of Mulato II and *D. intortum* forages in selected areas of Amhara Regional State, Northwestern Ethiopia. It provides insights on vital aspects which include utilization practices and constraints of production, agronomic performance, and replacement potential of Mulato II and *D. intortum* mixed forages to concentrate feeds in relation to growth performance, blood profiles, and enteric methane emissions of Farta rams. These interconnected objectives of the study form a cohesive framework aimed at enhancing sustainable sheep production. The utilization practices and constraints of Mulato II and *D. intortum* forages provides awareness into adoption and management strategies crucial for maintaining sustainable forage production. The agronomic performance of the forages further adds an understanding of the factors to be considered while forage production to achieve maximum yield and quality. Lastly, evaluating the effects of replacement of concentrates with Mulato II and *D. intortum* mixed forages on the growth performance of sheep not only enhances efficiency but also highlights effective resource utilization. Further, it helps to observe the health and environmental outcomes of those experimental feeds for sustainable livestock production. Together, these objectives emphasize the importance of a general assessment that integrates farmers' knowledge with scientific advancements to enhance sustainable forage production in terms of yield and quality in the farming system. This helps to unlock the potential and ensures a sustainable future for sheep productivity.

The survey work emphasized the assessment of the production and utilization practices of Mulato II and *D. intortum* forages by livestock farmers. It revealed that both of those forages have a multitude of functions for smallholder farmers in the study areas. Accordingly, those forages were used primarily as push-pull technology to control insect pests, animal feed followed by soil conservation in both of the study areas (**Chapter 3**). The production of those forages was done in association with PPT. Further, Mulato II grass performed well in infertile acidic soils and highly valued for the production of high dry matter yield (Reisinger and Clark, 2018) and encourage livestock production (Ondabu *et al.*, 2017; Reisinger and Clark, 2018).

However, farmers faced several challenges while cultivating the forages. Some of the major challenges were lack of land and scarcity of seed/planting material. In this regard, unavailability of *Brachiaria* seeds in local retail agents (Cheruiyot *et al.*, 2020) and the shortage of *D. intortum* seed (Khan *et al.*, 2014) were reported as the major constraints of *Brachiaria* grass and *D. intortum* forages production. Understanding the perceptions of farmers focusing the production and identifying the constraints would contribute for sustainable production of those forages thereby enhancing the livestock productivity.

The agronomic study focused on the agromorphological and nutritive potentials of Mulato II and *D. intortum* forages underlying with various factors (i.e, planting pattern, agroecologies, and harvesting ages). The findings of this research (**Chapters 4**) showed that these factors had effects on plant morphological characteristics and nutritive potentials on the forage species under study (Mulato II grass and *D. intortum*). The interaction effect of planting pattern, agroecologies, and harvesting ages resulted in the longest PHPP and LLPP, largest mean counts of NTPP, NLPP, and NRPP of Mulato II grass from the intercropped regimen at 120 days in the lowland agroecology. This is supported by previous study with similar observations in which morphological characteristics of *Brachiaria* grass are influenced by the interaction of various factors such as harvesting time and agroecology (Worku *et al.*, 2021; Tiruneh *et al.*, 2022).

Plant morphological characteristics such as number of tiller play vital role in herbage yield production (Luna *et al.*, 2016). According to Virkajärvi (2012), tiller production is an integral part of perennial grasses for continued forage production through replacing plant parts that are lost as a result of ageing, grazing, or cutting. It is an important morphological characteristic to be considered during selection of appropriate forage crop species for better improvement of production (de Lima Veras *et al.*, 2020). Forage quality and palatability is affected by the leaf to stem ratio. It has also shown to determine diet selection and intake in tropical grasses (Mganga *et al.*, 2021). Leaf to stem ratio (LSR) of grass stands is an important factor affecting diet selection, quality, and intake by ruminant animals (Smart *et al.*, 2004). It is essential to estimate forage quality and optimizing harvest times as harvesting time delayed its value is declined. Higher LSR

values resulted in improving animal performance due to its high nutritional value which enhance high dry matter intake (Onjai-Uea *et al.*, 2022). Besides, The Land Equivalent Ratio (LER) is a widely used metric in agricultural research to evaluate the productivity of intercropping or mixed cropping systems compared to monocultures. It quantifies the relative land area required under sole cropping (monoculture) to produce the same yield as an intercropping system (Deb *et al.*, 2022). LER is particularly valuable in assessing the efficiency of land use in systems such as forage production, where multiple species are grown together. LER value greater than 1 indicates that the intercropping system is more productive per unit of land than monoculture, implying a yield advantage due to better resource utilization (e.g., light, water, nutrients). LER less than 1 suggests that intercropping is less efficient, while an LER equal to 1 indicates equivalent productivity to monoculture (Mead and Willey, 1980). Thus, LER helps assess whether integrating forage crops with other species enhances overall biomass production compared to growing them separately. The value for the LER in the current study was greater than 1 which could imply the yield advantage of intercrop compared to monoculture and is comparable with previous study by Rahman *et al.* (2015).

D. intortum is a perennial tropical forage legume valued for its high-quality forage, nitrogen-fixing capabilities, and role in intercropping systems (Heuzé *et al.* 2017; Mengsitu *et al.*, 2017). According to Maina *et al.* (2006) reported that *D. intortum* has the potential to fix more nitrogen in the intercropping regimen but transfers only 5% of it to its companion grasses. Moreover, its agronomic trait such as plant height per plant, number of branches per plant, and number of root nodules are critical for its forage yield and overall productivity. In the current study, the PHPP (170.7 cm) recorded for intercropped *D. intortum* was higher than intercropped silverleaf desmodium (*D. uncinatum*) (60.5 cm; Anteneh, 2022) and sole stand silverleaf desmodium (*D. uncinatum*) (101.6 cm; Keba, 2023). This variation could partly be due to differences in environmental conditions (Kifuko-Koech *et al.*, 2012) such as soil fertility, ambient temperature, and management practices such as agronomic practices (Abebe *et al.*, 2022). A higher number of branches per plant increases leaf area and photosynthetic capacity, directly contributing to higher DM yield. *D. intortum* forms root nodules through a

symbiotic relationship with rhizobia, enabling biological nitrogen fixation and contributes in enhancing soil fertility and plant growth and thus its yield (Kifuko-Koech *et al.*, 2012).

Alike to the morphological characteristics, the nutritive value of the forages is an important element to delve into selection of fodder varieties for sustainable livestock production (Maleko *et al.*, 2019). Ruminant animals need two major nutrients namely, carbohydrates and protein which are essential for animal body growth, maintenance, reproduction, and production, e.g milk, beef, wool (NRC, 2001). However, there are various factors which affect the nutrient concentration of forages such as harvesting ages and environmental conditions where the forages grown. Chemical composition parameters such as CP and NDF contents are the most important components for forage quality. Higher CP content improves forage quality, supporting animal production and productivity. According to NRC (2001) and Van Soest, (1994), the minimum CP requirement for normal rumen function is 7% and the CP content of Mulato II grass meets this minimum requirement. The CP value (12.26%) recorded from intercropped Mulato II was higher than the figure (9.35%) reported by Ojo *et al.* (2013) for mixed stand Panicum maximum at 14 weeks of harvesting age in the lowland agroecology. The variation could partly be due to differences in environmental conditions, species and management (Walie *et al.*, 2022). On the other hand, the fiber content of forages is an indicator of its nutritive potential since it affects nutrient intake and digestibility (Katoch, 2022). Dry matter intake and digestibility are known to be affected by the NDF concentration in feeds (Peprah *et al.*, 2021). Higher NDF reduces digestibility and intake, as it occupies more rumen space and takes longer to degrade. The NDF content (71.9%) observed from sole Mulato II at 120 days of harvesting time in the lowland agroecology is supported by Waghorn and Clark, (2004) who stated that tropical (C4) grasses have higher NDF concentrations (often >50% of DM) having NDF exceeding 70% of their DM.

The highest DMY (17.04 t/ha) observed from the intercropped Mulato II harvested at 120 days in lowland agroecology might be due to the development of more tillers (Gelayenew *et al.*, 2020; Walie *et al.*, 2022). Further, full growth of roots, stems,

and leaves in plant developmental stages may contribute to variation in growth and yield of forage grasses (Zewdu *et al.*, 2002).

The IVDMD is an essential parameter to attest the nutritional quality which might be affected by various factors such as differences in soil fertility, temperature, management, and species. In addition, differences in maturity at harvest is also the most important factor affecting the digestibility of grasses (McDonald *et al.*, 2002) since it largely affects the leaf to stem ratio and deposition of lignin content. The observed results in this field experiment clearly demonstrate the importance of those factors (planting pattern, agroecologies, and harvesting ages) on sustainable production of forages for livestock. In general, the nutrient composition and quality of forage crops are highly dependent on the micro-environment and plant growth habits (Seleiman *et al.*, 2017).

The feeding experiment emphasized the effect of Mulato II and *D. intortum* mixed forages as a replacement to concentrates on the growth performance of Farta rams fed a basal diet of natural pasture hay. The chemical analysis of the feed ingredients used for this study showed that natural pasture hay (NPH) had the lowest CP value (6.38%) coupled with the highest NDF content (71.32%). Thus, it is below the minimum CP requirement (<7%) of ruminant animals to help the rumen microbes function normally (Van Soest, 1994; NRC, 2001). This could imply that ruminant animals which strive solely on low quality feeds should be supplemented with feeds containing appreciable nutrients such as protein and carbohydrates to fully exploit their potential. In this regard, Mulato II and *D. intortum* forages had adequate CP contents (10.5 and 14.49%), respectively and could be used to supplement low quality feeds for sustainable animal production. The total dry matter intake (TDMI g/day) showed no significant variation among the five treatment diets and it delineates the nutritional potential of those forages to substitute the concentrates. The TDMI (%BW) was also showed no significant variation among the five treatment diets. According to ARC, (1980), the recommended TDMI (%BW) is from 2 to 6% and thus, the values for the TDMI (%BW) in this study falls within the range. On top of this, most of the digestibility variables (DM, OM, CP and NDF) were not significantly affected by the inclusion of Mulato II and *D. intortum* forages as a replacement to concentrates. The quality of the forages is the primary factor

to determine the digestibility of feeds by ruminant animals (Katoch, 2022). The more the feed quality, the more is its digestibility. In due regard, the non-significant variation in digestibility parameters, such as crude protein (CP) content, indicates the comparable potential of these forage species to serve as viable alternatives to scarce and expensive concentrate feeds. The ADG (g/day) and FCE of the sheep were unaffected by the different treatment diets. This might be as a result of similarity in the TDMI and digestibility of nutrients such as the presence of nonsignificant effect of treatment diets on CP digestibility. Furthermore, the nonsignificant effect of treatment diets on body weight measurements is also observed in previous studies (Shitaneh *et al.*, 2021; Dida *et al.*, 2023). In this animal evaluation experiment, it can be concluded that all the five treatment diets positively enhanced the growth performance of Farta rams. This in turn, highlights the comparative nutritional potential of the Mulato II and *D. intortum* forage species to substitute the concentrate feeds which are scarce due to the higher prices associated elsewhere in the country.

Furthermore, research on blood hematology, biochemical profiles and enteric methane emission of sheep supplemented with Mulato II and *D. intortum* mixed forages highlights its great potential in animal nutrition. Evaluation of blood profiles in sheep is very important to inspect its health status. The presence of blood hematological and biochemical parameters within the normal range in this study, could dictate that the efficacy of those supplemental feeds for sheep nutrition since the replacement value of the forages didn't show any negative effect on the health of the experimental sheep.

Further, methane is a fermentation end product in the rumen and hind gut of ruminants. The production of methane results in a loss of up to 12% of the gross energy intake. Methane is a major source of greenhouse gas emission (Gerber *et al.*, 2013). Thus, assessment of enteric methane emission of sheep supplemented with Mulato II and *D. intortum* mixed forages play utmost role to investigate its impact on the environment. As a result, enteric methane emission of sheep supplemented with Mulato II and *D. intortum* mixed forages showed non-significant effect among treatment groups ($P>0.05$). The nonsignificant effect of replacing concentrates with Mulato II and *D. intortum* mixed forage indicates the potential of those forages to substitute the concentrates without any

adverse effect on the environment. Since good quality feeds such as concentrates are promising options to mitigate the methane emission of ruminants. In the current study, the enteric methane emission in sheep ranged from 35.1 to 36.3 ppm. This result was lower than that of Chagunda *et al.* (2013) who reported methane emission value of 68.9 ppm for sheep using the laser methane detector (LMD). This discrepancy might be due to differences in feed composition, level of feeding, and animal activities (Soren *et al.*, 2015).

CHAPTER 9: GENERAL CONCLUSIONS AND RECOMMENDATIONS

The interviewed farmers used *Brachiaria* and *D. intortum* forages in push-pull technology (PPT) to increase crop yield. Alongside, the forages produced in PPT were used to feed their livestock. They used those forage species as livestock feed, pest management, and soil conservation. But, land scarcity and shortage of seed/planting material were the major hindering factors for the production of those forages in both study areas. This survey study provides a key lesson to various stakeholders to undertake strong extension services and provision of planting materials for sustainable production and utilization of the forages. Thus, farmers could be assisted through training and providing planting materials to avert the existing feed shortage.

The study on the agronomic performance revealed that most of the morphological characteristics and nutritive values of Mulato II and *D. intortum* forages were significantly affected ($P < 0.05$) by the interaction effect of planting pattern, agroecology, and harvesting ages. The highest crude protein (CP) (12.3%) for Mulato II was recorded from the intercropped system which was harvested at 90 days in lowland. On top of this, the highest dry matter yield (DMY) (17.04 and 16.69 t/ha) was recorded from both intercropped Mulato II and *D. intortum*, respectively, which were harvested at 120 days in lowland agroecology. Thus, optimum DMY and nutritive value of Mulato II and *D. intortum* were achieved from the intercrop harvested at 120 days in low altitude.

The study on animal evaluation experiment indicated that the replacement of concentrate with Mulato II and *D. intortum* mixed forages had no significant effect on the growth performance and feed conversion efficiency of sheep. Consequently, supplementation of Mulato II and *D. intortum* mixed forages up to 80% could be used to replace the concentrate without any adverse effect on the growth performance sheep. The results in this study also revealed that except RBC count, all of the blood profiles tested and enteric methane emission of sheep were not affected by the replacement effect of the supplemental forages ($P > 0.05$). All the blood profile test results were found within the normal ranges for healthy sheep. As a result, the supplemental forages could be a good

alternative to potentially substitute the concentrate without any negative effect on both the health and environment.

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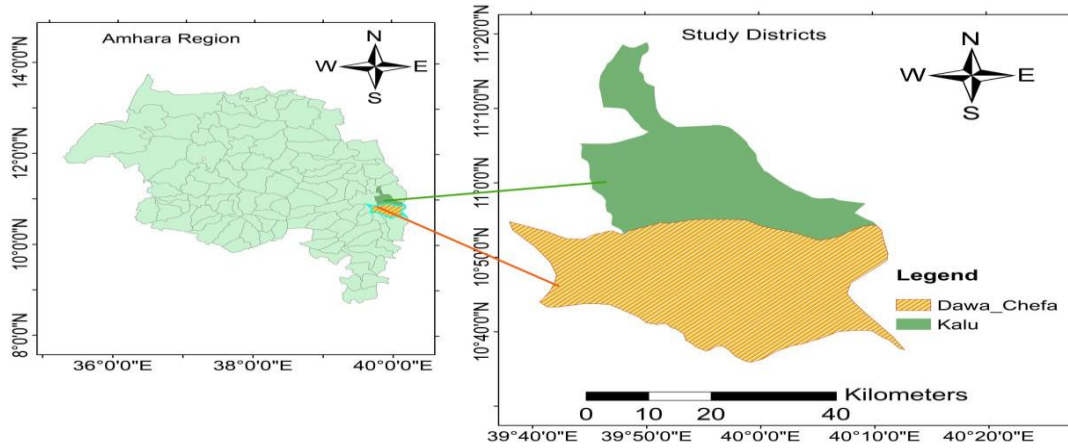
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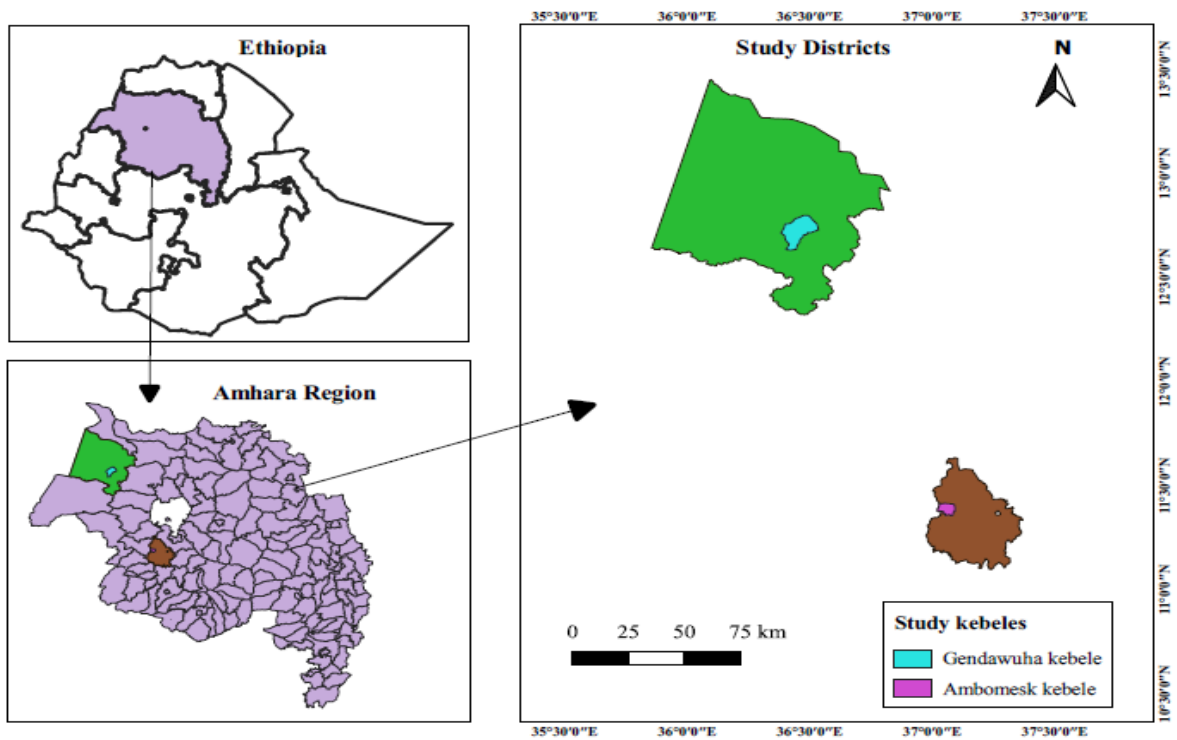
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APPENDIX

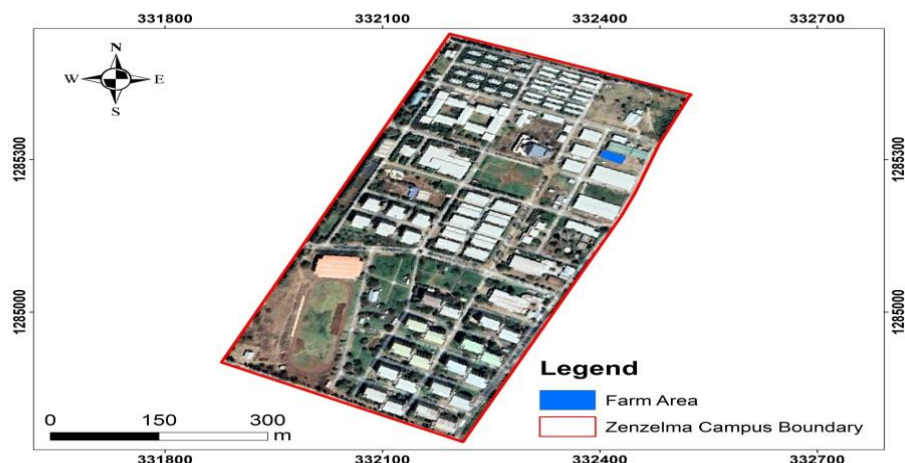
Appendix A. Study area maps



Appendix A Figure 1. Study area map for the survey work



Appendix A Figure 2. Study area map for agronomic study



Appendix A Figure 3. Study area map for animal evaluation experiments

Appendix B. Questionnaire

The objective of this questionnaire is to assess the **Production and Utilization practices of Mulato II and *D. intortum* forages by livestock farmers in selected areas of Eastern Amhara Regional state, Ethiopia.** The information obtained from interviewee through this questionnaire will be used only for academic purpose and the personal information will be kept confidential.

I, therefore, kindly request you to feel free in answering the questionnaire. Thank you.

1. General Information

Region	Zone	District	Kebele	Commencement
_____	_____	_____	_____	
Name of respondent	_____			
Sex	_____			
Age	_____			
Cell phone	_____			
Altitude	_____			
Date of interview	_____			

1. Socioeconomic characteristics

1.1. Household characteristics

1.1.1. Age, sex, educational profiles and family size of the household head

Age	Sex		Educational profile					Family size
	Male	Female	Illiterate	1-4	5-8	9-12	Certificate and above	
18-30								
31-40								
41-50								
51-60								
60+								

Use: 1 for male and 2 for female to refer sex; 1 for Illiterate, 2 for 1-4, 3 for 5-8, 4 for 9-12 and 5 for certificate and above to refer educational level

1.2. Farming characteristics

1.2.1 Occupation and landholdings

1.2.1. 1. What is your major occupation?

1. Crop farming only
2. Livestock farming only
3. Mixed farming and trading
4. Others (Specify)

1.2.1.2. How much is your total land holding (please specify the unit if different from hectare)?

1. Cultivated land (ha) _____
2. Grazing land (ha) _____
3. Fallow land (ha) _____
4. Cultivated fodder land (ha) _____
5. Others (specify) _____
6. Total land holding (ha) _____

1.2. 2. Livestock production

1.2.2.1. Do you have farm animals?

1. Yes
2. No

1.2.2.2. If your answer for Qn 1.2.2.1 is yes, indicate the type and current number of farm animals you have in the table provided below

Type	Number of animals				
	Local	Exotic	Crossbred	Total	TLU
Cattle					
Cow					
Ox					
Bull					
Heifer					
Small ruminant					
Sheep					
Goat					
Equine					
Donkey					
Mule					

Camel					
Poultry					

1.2.3. Purpose of livestock keeping

1.2.3.1. For what major purposes do you keep farm animals? (Rank in order of your priorities)

Purpose of livestock keeping	Cattle	Small ruminant	Equine	Poultry
Cash source				
Consumption				
Manure				
Draught power				
Transport				
Others (specify)				

1.2.3.2. Livestock production constraints by season (Rank in order of importance, 1-5)

Constraints	Feed shortage	Diseases	Poor breed performance	Water scarcity	Marketing problem	Others(Specify)
Wet season						
Dry season						

2. Livestock feed resources

2.1. What are the major feed resources for your animals? List in order of their coverage?

Major feed resources	
Wet season	Dry season

2.2. Do you face feed shortage for your animals? 1. Yes 2. No

2.3. If your answer is yes for question 2.2, at what season?

1. Wet season (June- October)
2. Dry season (Mid November- May)
3. Both

2.4. Based on Qn.2.3, what measures do you take to avert feed shortage?

1. Purchase concentrate feed
2. Rent grazing land
3. Purchase crop residues
4. Stock reduction
5. Minimize the amount of daily feed supply somewhere
6. Moving animals to somewhere
7. Others (specify)

2.5. Improved forage production and their utilization

2.5.1. Do you produce improved forages? 1. Yes 2. No

2.5.2. If your answer is yes for Qn.2.5.1, what types of improved forages do you produce?

Improved forage types	

2.5.3. How do you utilize the improved forages for your livestock?

1. Direct grazing
2. Green fodder/Cut and carry system
3. Hay
4. Silage

2.5.4. Major constraints of improved forage production and utilization (Rank in order of importance)

No.	Major constraints	Rank
1	Shortage of land	
2	Shortage of planting material	
3	Financial problem	
4	Drought	
5	Free grazing	
6	Poor extension services	
7	Others (Specify)	

2.5.5. Mulato II and Greenleaf desmodium (*D. intortum*) production and utilization

2.5.6. Are you experienced in the production of Mulato II and *D. intortum*?

1. Yes
2. No

2.5.7. Where do you get planting materials?

1. Government institutions
2. NGOs

3. Farmer to farmer
- 2.5.8. Where do you grow Mulato II and *D. intortum*?
1. In the border of PPT only
 2. Backyard and in the border of PPT
 3. Soil bund, roadside and stock exclusion areas and PPT
- 2.5.9. What are the planting materials for Mulato II and *D. intortum* forages?
1. Seed only
 2. Seedling (tillers) only
 3. Seed and seedling
- 2.5.10. When do you plant Mulato II and *D. intortum*?
1. Short rainy season (February- May)
 2. Main rainy season (June- mid September)
 3. Dry season (October – January)
- 2.5.11. When do you harvest Mulato II and *D. intortum* forages?
1. Short rainy season (February- May)
 2. Main rainy season (June- mid September)
 3. Dry season (October – January)
- 2.5.12. Do you apply fertilizer to the Mulato II and *D. intortum* during growing?
1. Yes
 2. No
- 2.5.13. If your answer is yes for Qn.2.5.12, what types of fertilizer do you apply?
1. Organic
 2. Inorganic
 3. Both
 4. Others (Specify)
- 2.5.14. Do you practice weeding?
1. Yes
 2. No
- 2.5.15. For what purpose do you use Mulato II and *D.intortum*?
1. Livestock feed
 2. Pest management
 3. Soil conservation
 4. Cash source
- 2.5.16. If it is for pest management to which crop are you growing those forages with?
- 2.5.17. What are major challenges in B. hybrid hybrid cv Mulato II and *D. intortum* production? Rank in order of importance

No.	Major constraints	Rank
1	Shortage of land	
2	Shortage of planting material	
3	Pricks and stick with cloth	
4	Leaf shuttering problem	

5	Lack of awareness	
6	Difficulty to clear land while needed	
7	Others (Specify)	

Appendix C. Livestock characteristics and feed resources

Appendix C Table 1. TLU conversion factors used to determine livestock holding per household

Livestock species	Conversion factor	References
Ox	1	(Strock <i>et al.</i> , 1991; Naseri and Kabul, 2005)
Cow	1	
Calf	0.34	(Strock <i>et al.</i> , 1991)
Heifer	0.8	(Naseri and Kabul, 2005)
Bull	0.6	
Sheep	0.13	(Strock <i>et al.</i> , 1991)
Goat	0.13	
Donkey	0.7	(Strock <i>et al.</i> , 1991; Naseri and Kabul, 2005)
Mule	1	(Strock <i>et al.</i> , 1991)
Camel	1.1	
Poultry	0.013	

Appendix C Table 2. Livestock holdings (TLU) by district

	Kalu		Dawa Chefa		
Livestock species	Mean	SD	Mean	SD	P value
Cattle					
Cow	1.5	0.92	1.92	1.13	0.007
Ox	2.00	0.54	2.14	0.61	0.094
Bull	0.77	0.57	0.89	0.38	0.099
Heifer	0.94	0.74	1.23	0.55	0.004
Calf	0.40	0.38	0.44	0.21	0.365
Total	5.61	2.19	6.62	1.50	0.000
Sheep	0.40	0.45	0.23	0.27	0.002
Goat	0.70	0.23	0.60	0.32	0.017
Total	1.11	0.53	0.83	0.50	0.000
Equine					
Donkey	0.33	0.35	0.31	0.35	0.656
Mule	0.40	0.49	0.33	0.47	0.444
Camel	0.27	0.48	0.39	0.53	0.105
Total	1.01	0.79	1.05	0.86	0.794
Chicken	0.15	0.08	0.08	0.06	0.000

SD= standard deviation; TLU= Tropical Livestock Unit

Appendix C Table 3. Purpose of livestock keeping by district

Purposes	Kalu								Dawa Chefa							
	Cattle		Small ruminant		Equine		Poultry		Cattle		Small ruminant		Equine		Poultry	
	I	R	I	R	I	R	I	R	I	R	I	R	I	R	I	R
Cash source	0.224	3	0.437	1	0.236	2	0.489	1	0.278	2	0.441	1	0.176	3	0.515	1
Consumption	0.239	2	0.315	2	0.041	5	0.372	2	0.235	3	0.282	2	0.006	5	0.402	2
Manure	0.110	4	0.248	3	0.085	4	0.139	3	0.081	4	0.277	3	0.134	4	0.083	3
Draught Power	0.427	1	-	-	0.211	3	-	-	0.406	1	-	-	0.256	2	-	-
Transport	-	-	-	-	0.427	1	-	-	-	-	-	-	0.428	1	-	-

I= index; R= rank; Index= sum of (4 times 1st order + 3 times 2nd order + 2 times 3rd order + 1 times 4th order...) for individual variables divided by the sum of (4 times 1st order+3 times 2nd order + 2 times 3rd order +1 times 4th order) for all variables

Appendix C Table 4. Livestock production constraints by district and season

Constraints	Kalu				Dawa Chefa			
	Wet season		Dry season		Wet season		Dry season	
	Index	Rank	Index	Rank	Index	Rank	Index	Rank
Feed shortage	0.331	1	0.333	1	0.292	2	0.327	1
Diseases	0.314	2	0.238	3	0.347	1	0.238	3
Poor breeding performance	0.203	3	0.069	5	0.228	3	0.105	4
Water scarcity	-	-	0.251	2	-	-	0.245	2
Marketing problem	0.152	4	0.109	4	0.133	4	0.085	5

Appendix C Table 5. Feed resources availability by season

Feed resources	Kalu				Dawa Chefa			
	Wet season		Dry season		Wet season		Dry season	
	Index	Rank	Index	Rank	Index	Rank	Index	Rank
Natural pasture	0.36	1	-	-	0.32	1	-	-
Hay	0.16	3	0.28	2	0.20	3	0.30	2
Crop residues	0.19	2	0.34	1	0.22	2	0.337	1
Concentrate	0.13	5	0.12	4	0.12	5	0.13	4
Improved forage	0.14	4	0.01	5	0.122	4	0.03	5
Fodder trees	0.01	6	0.236	3	0.01	6	0.19	3
Others	0.008	7	0.004	6	0.008	7	0.006	6

Appendix Table 6. Partial budget analysis

Variables	Treatments				
	T1	T2	T3	T4	T5
Sheep purchasing price (ETB/head)	4700	4300	4000	4000	4100
Selling price (ETB/head)	7800	7400	7200	7250	7350
Total grass hay consumed (kg/head)	91.875	89.67	89.30	88.2	86.36
Total conc consumed (kg/head)	42.58	33.99	25.39	16.82	8.20
Total grass-legume hay consumed (kg/head)	0	8.4	16.8	25.2	33.6
Feed cost					
Cost for grass hay (ETB)	459.4	448.4	446.5	441	431.8
Cost of concentrate (ETB)	937.4	743.3	580.4	425.0	220.9
Cost for grass-legume hay (ETB)	0	168	336	504	672
Labour cost	1600	1600	1600	1600	1600
Total variable cost (ETB/head)	2996.82	2959.6	2963	2970.0	2924.7

Total return (ETB/head) ¹	3100	3100	3200	3250	3250
Net return (ETB/head) ²	103.18	140.38	237.05	279.96	325.27
Change in NR		37.199	133.86	176.77	222.08
Change in TVC		-37.199	-33.862	-26.775	-72.083
MRR (%) ³		-100	-395.31	-660.22	-308.09

T1= NPH *ad libitum*+ concentrate only; T2= NPH *ad libitum*+ 80% concentrate+ 20% Mulato II and *D. intortum*; T3= NPH *ad libitum*+ 60% concentrate+ 40% Mulato II and *D. intortum*; T4= NPH *ad libitum*+ 40% concentrate+ 60% Mulato II and *D. intortum*; T5= NPH *ad libitum*+ 20% concentrate+ 80% Mulato II and *D. intortum*

¹ Total return= selling price minus purchasing price.

² Net return= total return minus total variable cost.

³ Marginal rate of return (MRR%)= (Δ net return/ Δ total variable cost)*100

Appendix D. Sample pictures



Figure 4.1. Mulato II and *D. intortum* forages grown around the border of maize crop

Source: Push-pull Team at Wollo University





Pictures taken during animal evaluation experiment

Figure 7.1. Methane emission measuring using laser methane detector (LMD) during the experiment