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Agronomic and Nutritional Value of Napier (*Pennisetum Purpureum* (L.) Schumacher) and Desho Grass (*Pennisetum Pedicellatum* Trin.) Integrated With Desmodium and Farmyard Manure As Well As Its Effect on Soil Properties of the Land in Upper Blue Nile Basin, Ethiopia

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BAHIR DAR UNIVERSITY

**COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES
DEPARTMENT OF ANIMAL SCIENCES, ANIMAL NUTRITION PHD PROGRAM**

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Trin.*) INTEGRATED WITH DESMODIUM AND FARMYARD
MANURE AS WELL AS ITS EFFECT ON SOIL PROPERTIES OF THE
LAND IN UPPER BLUE NILE BASIN, ETHIOPIA**

PhD Dissertation

By

Misganaw Walie Belete

March, 2023

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

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March, 2023

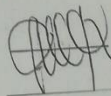
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As member of the Board of Examiners of the PhD Dissertation Open Defense Examination, we certify that we have read, evaluated the Dissertation prepared by Misganaw Walie entitled "Agronomic and nutritional value of Napier (*Pennisetum purpureum* (L.) Schumach) and desho grass (*Pennisetum pedicellatum* Trin.) integrated with Desmodium and farmyard manure as well as its effect on soil properties of the land in Upper Blue Nile basin, Ethiopia". We hereby certify that the dissertation is accepted for fulfilling the requirements for the award of the Degree of Doctor of Philosophy (PhD) in Animal Nutrition.

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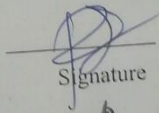


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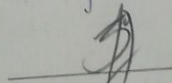


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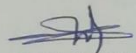
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DECLARATION

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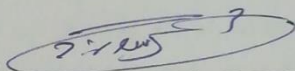
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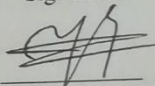
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DEDICATION

I dedicate this dissertation to my late father, Walie Belete, and my late mother, Aynabeba Getie, who worked tirelessly and invested in my education, but untimely passed away while I was halfway along. May GOD rest their soul in heaven!

ABBREVIATIONS

A: Pr	Acetate to propionate ratio
ADF	Acid Detergent Fiber
ADL	Acid Detergent Lignin
AGDP	Agricultural Gross Domestic Product
ANOVA	Analysis of Variance
AOAC	Association of Official Analytical Chemists
BD	Bulk Density
CAES	College of Agriculture and Environmental Sciences
CH ₄	Methane
Cm	Centimeter
CP	Crude Protein
CPY	Crude Protein Yield
CSA	Central Statistical Agency
DM	Dry Matter
DMY	Dry Matter Yield
EC	Electric conductivity
ECEC	Effective cation exchange capacity
EE,	Ether extract
EthioSIS	Ethiopian soil information systems
FAO	Food and Agriculture Organization of the United Nations
FYM	Farmyard Manure
GP24	24-h gas production
IVOMD	In vitro organic matter digestibility
JICA	Japan International Cooperation Agency
LL	Leaf length
LSR	Leaf-to-stem ratio
LW	Leaf width
m.a.s.l	meter above sea level
ME	Metabolizable energy
NRPP	Number of roots per plant

ABBREVIATIONS (*continued*)

NTPP	Number of tillers per plant
Pr	Propionate
P _{av}	Available phosphorous
PH	Plant height
RBV	Root biomass yield
RL	Root length
RSOC	Root soil organic carbon
RTN	Root total nitrogen
SAS	Statistical Analysis System
SATREPS	Science and Technology Research Partnership for Sustainable Development Project
SOC	Soil organic carbon
S: R	Shoot-to-root ratio
TVFA	Total volatile fatty acids
TN	Total nitrogen
VFA	Volatile fatty acids

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AGRONOMIC AND NUTRITIONAL VALUE OF NAPIER (*Pennisetum purpureum* (L.) Schumach) AND DESHO GRASS (*Pennisetum pedicellatum* Trin.) INTEGRATED WITH DESMODIUM AND FARMYARD MANURE AS WELL AS ITS EFFECT ON SOIL PROPERTIES OF THE LAND IN UPPER BLUE NILE BASIN, ETHIOPIA

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ABSTRACT

Inadequate supply and poor quality of available feed resources is the major challenges affecting livestock productivity in Ethiopian smallholder farmers. To combat this problem, field experiments were carried out in two watersheds of Ethiopia's Upper Blue Nile basin to assess the effects of farmyard manure (FYM) and *Desmodium intortum* (Green leaf Desmodium) intercropping on agronomic, nutritional value, and soil properties of Napier and desho grass, as well as their effects on natural pasture improvement. In the first experiment Napier (*Pennisetum purpureum* (L.) Schumach.) and desho (*Pennisetum pedicellatum* Trin.) grasses were evaluated on cultivated land under FYM and green leaf Desmodium intercropping for the morphological characteristics, dry matter yield (DMY), crude protein yield (CPY), nutritional value, in vitro gas fermentation, as well as their effects on soil physicochemical properties. For this field experiment Napier and desho grasses were planted at the Aba Gerima and Guder watersheds, which represent midland and highland agro-ecologies, respectively using randomized complete block design with factorial arrangements in three replications. The treatments used were Napier or desho grass alone [control], Napier or desho grass with green leaf Desmodium, Napier or

desho grass with FYM, and Napier or desho grass combined with green leaf Desmodium and FYM with a total of eight treatment combination. In the second field experiment, effects of FYM and enrichment planting with Napier and desho grass on natural pasture were evaluated at Aba Gerima watershed in terms of species composition, biomass yield, nutritional value, in vitro gas fermentation, and soil properties for two consecutive years. Natural pasture plots were treated with: Napier grass or desho grass, Napier or desho + FYM, Napier or desho + *Desmodium uncinatum* (Silver leaf Desmodium), and Napier or desho + FYM + *Desmodium uncinatum*; and untreated plots (natural pasture alone) were used as control with a total of nine treatments. The agronomic characteristics and laboratory data were subjected to two-way analysis of variance using SAS JMP-13. In the first experiment, the DMY and CPY were higher ($p < 0.001$) with FYM as well as FYM combined with green leaf Desmodium (9.1 to 9.6 t ha⁻¹ and 866.7 to 792.4 kg ha⁻¹) at Aba Gerima and (7.0 to 7.1 t ha⁻¹ and 795.3 to 510.5 kg ha⁻¹) at Guder, respectively. For Napier grass and desho grass there was an improvement in vitro organic matter digestibility (IVOMD) (6.7 vs 4.7%), metabolizable energy (ME) (5.5 vs 4.5%), and volatile fatty acids (VFA) production (23.1 vs 3.0%) in the green leaf Desmodium plus FYM treatments over the control at Aba Gerima. Moreover, the fertilizer treatments at cultivated land, i.e., *Desmodium intortum* plus FYM groups, showed soil organic carbon (18.4% and 20.5%) and available phosphorous (16.3% and 23.0%) content increments over the control in the same watershed. For the grazing land experiment, biomass yield in the desho + FYM + Silver leaf Desmodium plots (8.4 t ha⁻¹) was higher ($p < 0.001$) than natural pasture with Napier grass (5.9 t ha⁻¹), desho grass (6.5 t ha⁻¹), and control (4.4 t ha⁻¹). In addition, grazing land plots treated with Napier + FYM, Napier + Silver leaf Desmodium, and desho + FYM + Desmodium showed soil organic carbon levels that were significantly higher than controls. The findings suggested that green leaf Desmodium plus FYM improves growth, yield, nutritional value, IVOMD, and VFA production by maintaining soil fertility in Ethiopia's Upper Blue Nile basin, facilitating their growth in cultivated land as alternative livestock feed for better production in these areas. Furthermore, desho + FYM + Silver leaf Desmodium produced the greatest improvement in grazing land biomass yield and IVOMD by maintaining soil fertility in the study area.

Key words: Desmodium; Dry matter yield; Farmyard manure; Herbaceous species; Intercropping; In vitro gas production; Natural pasture; Volatile fatty acid

CHAPTER 1. GENERAL INTRODUCTION

1.1 Background and Justification

In the tropics, livestock production is an important economic activity that produces both food and non-food commodities. Ethiopia is endowed with huge livestock resources in Africa encompassing 70.3 million cattle, 42.9 million sheep, 52.5 million goats, 2.15 million horses, 10.8 million donkeys, 0.38 million mules, 8.1 million camels, and 57.0 million poultry (CSA, 2021). The contribution of livestock to national economy has been estimated to be about 10% to total export earnings, primarily through the export of ruminant animals (FAO, 2019). Furthermore, the sector accounts for 45% of agricultural gross domestic product, including economic values and non-marketed services such as draft power and manure (FAO, 2019) and 37% to 87% of household income (Behnke and Metaferia, 2013). In addition, livestock contribute a certain degree of security during crop production failure, as they are a “near-cash” capital stock. It also provides benefits such as fuel and fertilizer from animal manure and draught power for farm production (Smith *et al.*, 2013). Despite its significant contribution, livestock productivity in Ethiopia is lower than the African average, owing primarily to feed shortages both in quality and quantity (Abebe Mekoya *et al.*, 2008; Ahmed Hassen *et al.*, 2010; Bizelew Gelayenew *et al.*, 2020). To exploit the potential of livestock in sustainable manner, use of improved forages is one of the strategies in Ethiopia small holder farmers (Adugna Tolera *et al.*, 2012).

The major feed resources in Ethiopia are grazing pasture, crop residue, improved feed, hay, by-products, and others, which contribute 54.5%, 31.1%, 0.57%, 7.4%, 2.0%, and 4.4% of the feed demand, respectively (CSA, 2021). The first two are the country's main feed resources, and while they are low in nutritional value, they cannot meet the needs of ruminant animals. However, the high rate of human population growth is driving land use conversion, and cropland has increased by 0.4% per year while grazing land has decreased by 3.5% per year (Wuletaw Mekuria *et al.* 2018), in this case grazing and browsing lands are steadily shrinking from time to time due to poor management and encroachment of crop cultivation. Moreover, Fekede Feyissa (2013) reported that pasture lands have been significantly dwindled, highly fragmented, limited to areas where conditions are adverse for cropping due to topographic,

edaphic, and climatic limitations in the highlands and continuously shrinking due to human and livestock population pressure. The available grazing lands are also vulnerable to degradation and consequently become barren and gullies due to poor management. In addition, the seasonal fluctuation of rainfall, poor grazing land management, low soil nutrient levels, and poor forage species diversity (Abule Ebro, 2015) leads to low dry matter yield, crude protein (<5%), and metabolizable energy content which results in a critical shortage of animal feed, below the maintenance requirement of livestock (Endale Yadessa *et al.*, 2016). This decrease is accompanied by an increase in the role of crop residues, which are generally of low nutritional value (Zerbini and Thomas, 2003), which in turn is illustrative for exploring alternative feed resources.

To overcome this problem several forage crops have been tested in different agro-ecological zones, and considerable efforts have been made to test the adaptability of different species of forage crops under varying agro-ecological conditions (Alemayehu Mengistu *et al.*, 2017). The selected forage crops are generally well adapted to the different agro-ecologies and high yielding, and have better quality compared to natural pasture (Getnet Assefa, 2012). Accordingly, Napier grass (*Pennisetum purpureum*) has been recommended for fodder production and gaining acceptance and popularity in areas ranging from lowlands to the cooler parts of Ethiopian highlands (Fekede Feyissa *et al.*, 2005). In addition, desho (*Pennisetum pedicellatum*) which is an indigenous forage grass is a highly popular, drought-tolerant species, and is used as one of the major feeds for ruminants in the high lands of Ethiopia (Bimrew Asmare *et al.*, 2017). Conversely, the legume *Desmodium intortum* has been introduced and is being grown on various land uses as a mixed pasture, with multiple advantages over the monoculture of forage grasses (Alemayehu Mengistu *et al.*, 2017). The common benefits of *Desmodium* includes forage production, nitrogen fixation, and soil erosion control (Alemayehu Mengistu *et al.*, 2017). The components of grass/legume mixtures have the ability to utilize the limited resources more efficiently than when grown in pure stands, thus, showing resource complementarities (Atis *et al.*, 2012).

Grasses and legumes are important forage crops due to their nutritional value, particularly protein content in legumes and crude fiber in grasses, which may be available in the rumen for

proper fermentative digestion (Rakeih *et al.*, 2010). Though, monocultures of legumes or grasses do not provide satisfactory results for forage production and nutritive value (Lithourgidis *et al.*, 2006). However, the contribution of improved forages to livestock feed resources at national level was less than 1% (CSA, 2021). According to Lemma Gizachew *et al.* (2010), only 0.15% of smallholder farmers practice on-farm improved forage production. Land shortage, low access and high cost of seed and planting materials, and lack of awareness of their importance and production are the major impediments to low practice of improved forage production by smallholder farmers (Alemayehu Abebe *et al.*, 2018; Shimelis Mengistu *et al.*, 2021).

The growth, yield, and nutritive value of forage crops are affected by various factors such as soil fertility, agro-ecology, fertilizer type, forage species, harvesting stage, land preparation, and management systems. The most anthropogenic factors which greatly contribute for soil fertility deterioration are deforestation, overgrazing, land-use changes, and cultivation on steep slopes (Lal, 2015), which results in reducing the productivity of agricultural land, and affects the livelihoods of smallholder farmers (Moges Tadesse, 2020). In this regard addition of major soil nutrients is essential for achieving high crop yields, but excessive and/or imbalanced nutrient inputs may pose risk pressure on the environment, human health, and ecosystems. In addition, continuous use of inorganic fertilizers causes deterioration in soil chemical, physical, and biological properties, as well as soil health, which combined with rising prices, has sparked interest in the use of organic fertilizers such as farmyard manure (FYM) as a source of nutrients (Mahajan *et al.*, 2008).

On the other hand, fertilizer application for forages in Ethiopia are not uniform in terms of application or fertilizer form (Bimrew Asmare *et al.*, 2016). The amount of chemical fertilizer applied to crop production is low in Ethiopia due to its high cost for resource-poor smallholder farmers (Kefyalew Endale, 2016), despite the fact that the majority of farmers do not use fertilizer for forage production. Conversely, inorganic fertilizers do not last long in the soil and must be reapplied frequently in every production time. Farmyard manure is an organic fertilizer that improves the chemical properties of the soil, specifically nitrogen (N), phosphorous (P), and potassium (K), allowing for increased growth and sustainable production (Eghball *et al.*,

2004). According to Brady (1990), about 50% N in most animal manures is available for plant uptake during the first year of application. Many studies have been conducted worldwide on the effect of fertilizers toward the performance of fodder plant species. For example, Maleko *et al.* (2019) conducted an experiment in Tanzania and reported that application of FYM had increased the biomass yield of the *Brachiaria ruziziensis* by 1.3, 4.19, and 4.39 t ha⁻¹ when manure was applied at the rate of 5, 10 and 15 t ha⁻¹ respectively. Thus, integrating FYM and Desmodium with forage grasses increase the availability of quality and quantity feed for sustainable livestock production.

Despite efforts to improve available grazing land productivity, herbage yield and nutritional quality of natural pasture in Ethiopia are generally low (Shiferaw Yalew *et al.*, 2020; Tesfay Atsbha *et al.*, 2020) due to poor management and utilization. In addition, seasonal fluctuation in the availability and quality of natural pasture is a common phenomenon in Ethiopian condition (Solomon Bogale *et al.*, 2008). Productivity of natural pasture lands ranges very low less than 0.5 t ha⁻¹ up to more than 8 t ha⁻¹ but most natural pasture lands produce about 2 t ha⁻¹ y⁻¹. The metabolizable energy (ME), crude protein (CP) and dry matter (DM) contents of these natural pastures in most cases have been reported to be below the maintenance requirement of the animal in Bale highlands (Solomon Bogale *et al.*, 2008). Generally, there is a severe shortage of grazing resource together with marked decline in the productivity and quality of the natural pasture in the highlands of the country (Tessema Zewdu *et al.*, 2010b; Shiferaw Yalew *et al.*, 2020). On the other hand, Tessema Zewdu *et al.* (2011) found that grazing land with light grazing had higher organic carbon, phosphorus, and exchangeable bases, indicating an improved soil nutrient status when compared to heavily grazed land in Ethiopian semi-arid savanna. The same author also mentioned that better soil nutrients are associated with higher basal cover and standing biomass at lightly grazed sites. This problem inevitably necessitates increasing the productivity of the country's grazing lands through appropriate management interventions.

Application of improved grazing systems like fertilization, reseeding, proper harvesting, conservation and utilization practices are very pertinent (Alemayehu Mengistu, 2004). According to the report of Conant *et al.* (2001) use of different management methods for

improving grass lands from 115 studies and reported that fertilization (39%) and native vegetation (15%) are most common, whereas sowing legumes (4%) and grasses (2%) are the least common. On the other hand, time of harvest and soil fertility are the main factors that limit biomass yield and nutritive value of pasture lands (Tessema Zewdu. *et al.*, 2010b). Different authors (Tessema Zewdu. *et al.*, 2010b; Tesfay Atsbha *et al.*, 2020) reported that application of both inorganic and organic fertilizer (manure) increased biomass yield, nutritional value, and botanical composition of natural pasture. However, no research has been conducted on improving grazing land management through integrated use of FYM and enrichment planting with improved forages for increased biomass yield, nutritional value, and volatile fatty acids by maintain soil fertility.

Several researchers reported that FYM and legume intercropping improved forage morphological characteristics, biomass yield, nutritive value, and soil physicochemical properties (Tessema Zewdu *et al.*, 2002; Utamy *et al.*, 2018 ; Maleko *et al.*, 2019; Ma *et al.*, 2020). On the other hand, chemical composition, IVOMD, and VFA production are useful feed evaluation indicators for ruminant livestock production ration balancing. In this regard, evaluation of forage quality is important for the prediction of animal performance and to implement appropriate management strategies for its exploitation (Mountousis *et al.*, 2008). However, there is limited research on the extent to which integration of forage grasses with FYM and legumes like *Desmodium intortum* as fertilizer treatments affects the growth, yield, and nutritional value of forage grasses as well as its association with each other in cultivated land. Moreover, there is limited information on soil physicochemical properties under different climatic conditions for longer production times in northwestern Ethiopia. Conversely, planting Napier or desho grass on the existing natural pasture (enrichment planting with Napier or desho grass) with FYM application affects biomass yield, species composition, nutritional value, and soil physicochemical properties was not addressed well in the study area. Therefore, the goal of this study was to improve the availability and quality of livestock feeds for better production and productivity through integrated application of FYM and *Desmodium* intercropping as fertilizer treatments using selected forage grasses in the Upper Blue Nile basin, as well as to identify management practices that can reduce grazing land degradation and thus improve biomass yields, nutritional value and species composition by maintaining soil health.

1.2 Research objectives and Hypothesis

Objectives

Therefore, this study was initiated with the following objectives:

General objective

- To investigate the influence of farmyard manure and *Desmodium* intercropping on growth characteristics, yield, nutritional value, in vitro VFA production, and soil physicochemical properties of Napier and desho grasses in Upper Blue Nile basin, Ethiopia

Specific objectives

- ✓ To investigate the effects of FYM and *Desmodium intortum* intercropping on the growth characteristics, yield, and soil physicochemical properties of Napier and desho grass in cultivated land under different agro-ecologies
- ✓ To evaluate the effects of FYM and *Desmodium intortum* intercropping on chemical composition, nutritive value and in vitro volatile fatty acid production of Napier and desho grass in two different agro-ecologies grown on cultivated land.
- ✓ To evaluate the effects of enrichment planting with Napier and desho grass with FYM application on biomass yield, nutritional value, and soil nutrient status of natural pasture in north western Ethiopia

Research Hypothesis

Based on the above background and justification, we tested the following hypothesis:

Integration of *Desmodium* and farmyard manure with Napier and desho grass

1. Improves the growth characteristics, yield, and soil physicochemical properties of forage grasses
2. Results an increase in chemical composition as well as in vitro organic matter digestibility and volatile fatty acid production of Napier and desho grass
3. Results an increase in herbaceous species composition, biomass yield, nutritional value and soil fertility in grazing land management condition

1.3 Organization of the Dissertation

There are seven chapters in this thesis (Fig. 1.1). The introductory portions are presented in the first chapter (Chapter 1. General Introduction). It is concerned with the general introduction section, which provides background information. It describes theoretical data about the potential and contribution of livestock sub-sector to the national economy and at the household level. It also discusses Ethiopia's livestock feed resources and production difficulties.

Chapter two- covers the literature review, which provides detail of the justification on how the parameters measured affected in relation to other scientific studies across the world. In this part it also focus on feed resources, their contribution and major problems for use as livestock feed. In addition, the origin and distribution of studied forage grasses (Napier and desho grass) and major environmental factors affecting growth and nutritional value of such forage grasses.

Chapter three- The general materials and methods used are explicitly mentioned, including experimental site descriptions, planting materials, experimental design and treatments, data collection methods, and soil and plant sample analysis.

Chapter four- covers evaluation of Napier and desho grass growth characteristics, yield, and soil physicochemical properties (using farmyard manure and *Desmodium intortum* intercropping as fertilizer treatments) in two different watersheds representing midland and highland agro-ecologies of the Upper Blue Nile basin, Ethiopia.

Chapter five – this study looked at the effects of farmyard manure and *Desmodium intortum* integration on the chemical composition, in vitro gas fermentation, and volatile fatty acid production of Napier and desho grass in two different agro-ecologies in the Upper Blue Nile basin watersheds.

Chapter six – deals with improvement of degraded natural pasture through farmyard manure application and enrichment planting with Napier and desho grass for enhanced biomass production, species composition, nutritional value, in vitro gas fermentation, and soil physicochemical properties.

Chapter seven- presents the summary, conclusions, and recommendations for further research. The current study as a whole insight some clear conclusions, the implications of the research, and some suggestions for future research.

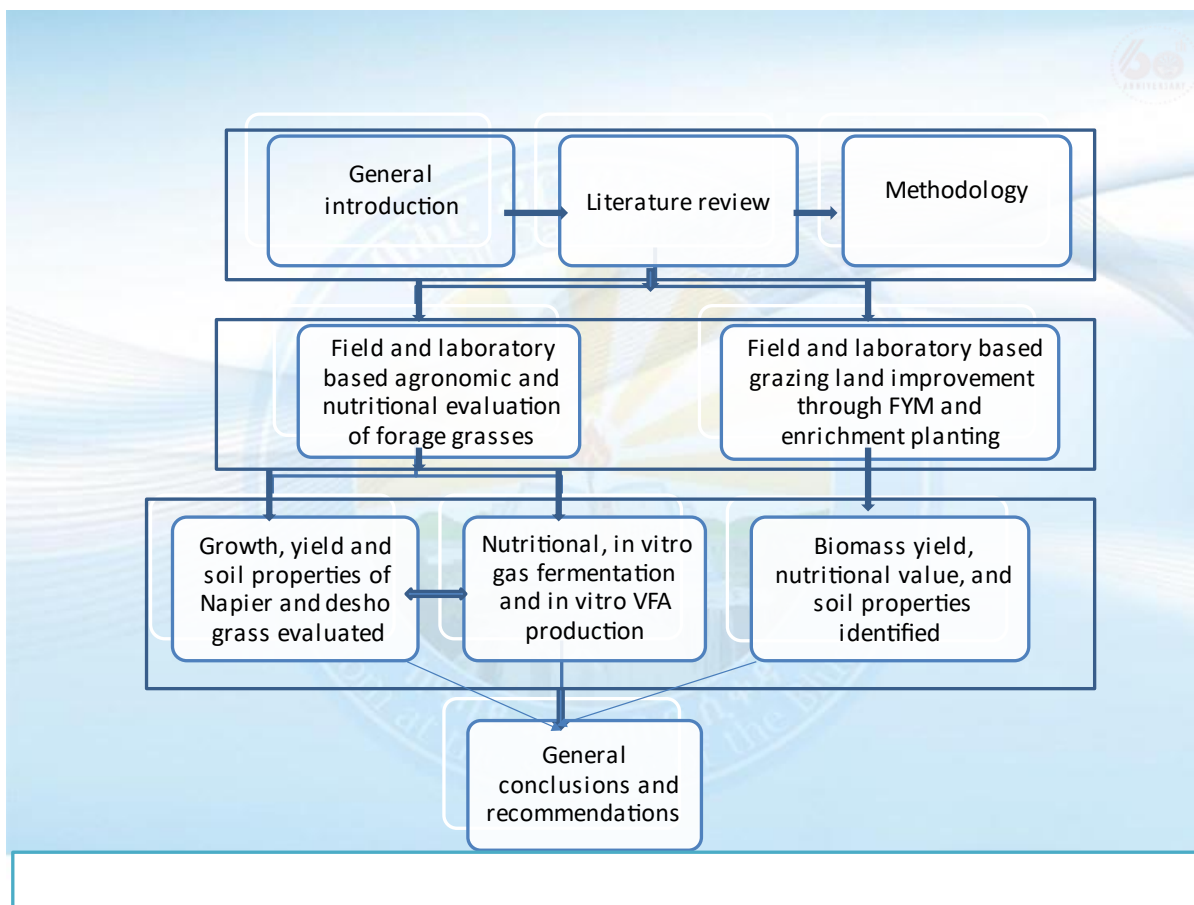


Figure 1.1 The structure of the thesis

CHAPTER 2. LITERATURE REVIEW

2.1 Feed Resources and utilization in Ethiopia

Feed availability and quality are two major factors limiting livestock productivity in Ethiopia. Natural pasture grazing, crop residues and aftermath grazing, improved pasture, fodder trees and browse, forage crops, and agro-industrial by-products are the major feed resources in Ethiopia, with the first two accounting for the lion's share (CSA, 2021). Apart from these feed resource classifications, natural pastures from river and road sides, as well as weeds from crop production, are used as animal feed sources (Ahmed Hassen *et al.*, 2010). According to the same author, despite the country's diverse feed resources for livestock production, they are insufficient in terms of quantity and quality, particularly during the dry seasons. Conversely, the contribution of natural pasture and crop residue as livestock feed varies by region and cropping intensity, population pressure, agro-ecology, season of the year, and environmental conditions (Angaw Tsigie *et al.*, 2011).

2.1.1 Natural Pasture

Natural pastures are the primary feed source available in most areas of Ethiopia for the majority of the year in smallholder production systems (CSA, 2021). According to the same source, grazing on natural pasture accounts for approximately 54.5% of total feed resources. However, due to the high rate of human population growth, cropland has increased by 0.4% per year while grazing land has decreased by 3.5% per year (Wuletaw Mekuria *et al.* 2018). In this case, grazing and browsing lands are steadily shrinking due to poor management and crop cultivation encroachment. Most of these native pastures are now confined to degraded, shallow upland soils, fallow crop land, and soil that cannot be cropped successfully due to physical constraints such as flooding and water logging (Alemayehu Mengistu, 2004). Forage yield and nutritional quality of pasture, on the other hand, are influenced by a variety of factors, including cutting frequency, species composition, plant maturity stage, climatic conditions, soil fertility status, and harvesting season (Yihalem Denekeew *et al.*, 2005).

Natural pastures in Ethiopia's highlands are diverse in terms of species composition, particularly indigenous grasses and legumes (Yihalem Denekeew *et al.*, 2005). The dominant species in

northwestern Ethiopian natural pasture were *Andropogon*, *Avena*, *Eragrostis*, *Eleusine*, *Cynodon*, *Cyperus*, *Digitaria*, *Hyparrhenia*, *Pennisetum*, *Setaria*, *Trifolium* and *Medicago* (Tessema Zewdu, 2003b). Even though, the diverse species composition has an opportunity for better yield and nutritional value; the seasonal fluctuation of rainfall, poor grazing land management, and low soil nutrient levels (Abule Ebro, 2015) leads to low dry matter yield, crude protein (<5%), and metabolizable energy content which results in a critical shortage of animal feed, below the maintenance requirement of livestock (Endale Yadessa *et al.*, 2016). On the other hand, the practice of applying fertilizer inputs on an unimproved natural pasture is limited in tropical grasslands. Thus, appropriate grazing land management practices should be implemented to improve herbage yield and quality and ultimately animal productivity in the highlands of crop-livestock mixed farming systems.

2.1.2 Crop Residues and aftermath

Crop residues are fibrous byproducts of cereal, pulse, oil plant, root, and tuber cultivation that are valuable feed resources in the northern parts of Ethiopia (Yayneset Tesfay., 2010). According to the same author, crop residues are used as livestock feed in almost all crop-livestock mixed farming systems. Furthermore, it is critical for full filling feed gaps when other feed resources are scarce. Crop residues account for approximately 31.1% of total feed supplied in Ethiopia, according to (CSA, 2021). Crop residue production is highly dependent on grain production, farming system, crop type, and cultivation intensity. They are potentially rich sources of energy, with polysaccharides accounting for approximately 80% of their dry matter (DM), but they are typically underutilized due to their inherent low digestibility, which limits feed intake (Daniel Keftasa, 2008).

Plant morphological components (leaf: stem ratio) and crop variety influence the nutritive value of crop residues (Adugna Tolera *et al.*, 2000). As has been documented, as more land is dedicated to crop production, crop residues become the primary feed source for animals, particularly during the dry season (Daniel Keftasa, 2008). However, the possibility of using crop residue for various purposes, such as fuel as firewood, house construction, roofing local houses, and as a binding material for walls, may result in competition for the use of this resource.

The combined effect of these factors has reduced crop residues' contribution as livestock feed (Angaw Tsigie *et al.*, 2011).

On the other hand, crop residues are generally of poor nutritive value (Zerbini and Thomas, 2003). They are characterized by high fibre content ($>700 \text{ g kg}^{-1}$ of cell wall), low DM digestibility ($<50\%$), low metabolizable energy ($<7.5 \text{ MJ kg}^{-1} \text{ DM}$), low concentrations of crude protein (CP) ($<60 \text{ g kg}^{-1} \text{ DM}$), and low voluntary dry matter intake (Adugna Tolera *et al.*, 2000). In addition, the major challenge with crop residue is to develop ways for increasing feeding value, particularly nitrogen content, digestibility and intake potential, in order to increase animal production in crop residue-based feeding systems (Ertiro *et al.*, 2013). In this regard a number of research, development and extension works have been done, particularly in the tropics, to improve the nutritive value of crop residue as ruminant feedstuffs. Among the treatments used physical like chopping, chaffing, crushing and grinding, and chemical treatments like treatment with steam, alkali or ammonia, and biological treatments with fungi or enzymes (McDonald *et al.*, 2000). However, treatments for improvement of crop residue have not been widely adopted due to the constraints related to the involvement of substantial input costs and labour for preparing to be used as livestock feed. Hence, there is a need for alternative feed source which are better in nutritional value to complement the available crop residue for better livestock production and productivity.

2.1.3 Improved Forages

Improved pasture and forages have been grown and used in government ranches, state farms, farmer's demonstration plots and dairy and fattening areas. Forage crops are commonly grown for feeding dairy cattle with oats and vetch mixtures, fodder beet, Napier grass mixed with Siratro and Desmodium species, Rhodes/Lucerne mixture, Phalaris/Trifolium mixture, hedgerows of Sesbania, Leucaena and Tree-lucerne being common ones (Alemayehu Mengistu, 2004). However, there has been limited introduction of improved pasture and forages to smallholder farming communities and the adoption of this technology by smallholder mixed farmers has been generally slow (Abebe Mekoya *et al.*, 2008).

The dry matter yield and nutritional value of Napier grass influenced by soil fertility, fertilizer type, harvesting stage, frequency of defoliation, and climatic condition. In addition, the dry matter yield of Napier affected by plant height at cutting and fertilizer application (Tessema Zewdu *et al.*, 2002). The author added the highest digestible DM yield obtained at cutting 1.0 m and 1.5 m height while the digestibility declined at later harvest. In addition, it had higher DM, CP and in vitro dry matter digestibility values at an intermediate frequency of defoliation (90 days after Napier grass establishment) than early and delayed cutting intervals (Tessema Zewudu *et al.*, 2010a). Application of manure at 184 kg N ha⁻¹ y⁻¹ resulted better dry matter yield and in vitro dry matter digestibility and improved soil chemical properties and total nitrogen and carbon content for sustainable dwarf Napier grass production (Utamy *et al.*, 2018).

The nutritional value of desho grass vary depending up on soil type, agro-ecology, fertilization, and stage of harvesting. According to the report of Bimrew Asmare *et al.* (2017), both altitude and harvesting date affected the CP content, yield and fiber fractions of the grass; a higher CP content at early harvest in mid altitude while the lowest at later harvest in high altitude areas. The same author added fiber fractions content neutral detergent fiber (NDF) and acid detergent fiber (ADF) differ in altitude and harvesting stages; NDF content was higher for desho grass planted at mid altitude in late harvesting while it was comparatively lower for earlier harvesting in the high altitude agro-ecology.

2.1.4 Agro-industrial by-products

Agro-industrial by-products contribute as animal feed sources with higher nutritional value and lower fiber constituents (Fekadu Abate, 1999). However, its contribution to the total animal feed resource is limited to 2.03% (CSA, 2021). Agro-industrial by products result from the processing of crops such as flour meals, oil seeds, sugarcane, sisal, citrus, pineapple and bananas; or the slaughter by products and processing of livestock and fish. They are rich in protein (oil seeds and meals of animal origin) or energy (molasses and citrus) and usually low in fiber (Fekede Feyissa *et al.*, 2015).

Several complementary and alternative strategies can be pursued in tropical regions with the objective of making low quality feeds more useful for production of meat and milk. Concentrate

feed supplementation is one strategy, which can increase digestibility, nutrient supply and intake (Abeba Nega and Solomon Melaku, 2009). Maximization of livestock productivity in the tropical regions largely depends on the efficiency of utilization of local protein sources (Seyoum Bediye *et al.*, 1996). However, concentrate feed sources especially grains are expensive and highly valued as human food. Agro-industrial by-products, are mostly used to supplement low quality feed resources, but they become costly for smallholders to afford and might not be cost effective as they used in commercial production purpose by investors. Therefore, it is necessary to look for other alternative feed source with better biomass yield and nutritional value to sustain and improve animal productivity.

2.2. Improvement of Natural Pasture

The herbage yield and nutritional quality of natural pasture is generally low due to poor management and utilization (Adane Kitabe and Birhan Tamir, 2005; Tessema Zewudu *et al.*, 2010b). In addition, seasonal fluctuation in the availability and quality of natural pasture is a common phenomenon (Solomon Bogale, 2004). In this regard, productivity of natural pasture lands ranges very low less than 0.5 t ha^{-1} up to more than 8 t ha^{-1} but most natural pasture lands produce about $2 \text{ t ha}^{-1} \text{ y}^{-1}$. Generally, there is a severe shortage of grazing resource together with marked decline in the quality of the natural pasture in the highlands of the country (Adane Kitabe, 2003). This problem inevitably calls for improving the productivity of the grazing lands in the country through appropriate management interventions. Application of improved grazing systems, fertilization, reseeding, proper harvesting, conservation and utilization practices are very pertinent (Alemayehu Mengistu, 2004).

The yield of the natural grasslands increases with increasing levels of fertilizer application up to 125 kg ha^{-1} regardless of decline in overall production due to frequent grazing and cuttings in one growing season (Tessema Zewudu *et al.*, 2010b). The same author justified that the dry matter yield of fertilized plots of natural pasture has been shown to be 9.47 t ha^{-1} as compared to unfertilized plots 5.67 t ha^{-1} at 90 days of harvest. Conversely, Adane Kitabe and Birhan Tamir (2005) reported that early harvesting and nutrient application resulted in higher nutrient concentration of forages in the pasture. The same author showed harvesting at 30 days of growth stage with nutrient levels above $22.5 \text{ kg N} + 25.9 \text{ kg P ha}^{-1}$ increased the nutritive values of

forages. Moreover, harvesting of forage species at early stage of growth with proper grazing management (Zinash Sileshi *et al.*, 1995) and application of inorganic fertilizer to natural pasture lands are among the strategies towards improving the nutritive values of natural pasturelands (Adane Kitabe and Birhan Tamir, 2005). On the other hand, time of harvest and soil fertility are the main factors that limit biomass yield and nutritive value of pasture lands (Tessema Zewdu *et al.*, 2010b). Different authors (Tessema Zewdu *et al.*, 2010b; Tesfay Atsbha *et al.*, 2020) reported that application of both inorganic and organic fertilizer (manure) increased biomass yield, nutritional value, and botanical composition of natural pasture.

The amount of DM produced for each kilogram of nitrogen applied depends largely on the species under consideration, frequency of defoliation and growth condition (Miles and Manson 2000). According to the report of Fekadu Nemera *et al.* (2017) a higher proportion of legumes under cattle manure and wood ash in the degraded grazing land, in the central highland of Ethiopia. In addition, herbage dry matter yield increased from 1.88 to 6.65 t ha⁻¹ with inorganic fertilizer while the CP content increased from 96 to 157 g kg⁻¹ with manure application (Nebi Bedaso *et al.*, 2022). The same author reported that the NDF tended to decrease following manure application. Tesfaye Atsbha *et al.* (2020) and Shiferaw Yalew *et al.* (2020) reported a higher proportion of forbs in the unfertilized treatment group. On the other hand, grasses may be stronger competitors for available nitrogen, permitting an increased rate of growth, leaf expansion, and tillering, followed by suppression of the legumes by shading (Miles and Manson 2000). The same author added, phosphorus fertilizer must be applied to deficient soils for establishment and long-term maintenance of legumes in the pasture. Moreover, application of different fertilizer inputs offer feasible options to improve pasture productivity with positive economic gain from the direct sale of pasture hay and enable rural farmers to benefit from their land resources (Nebi Bedaso *et al.*, 2022).

2.3 Effect of environmental factors on plant growth and chemical composition

Plant growth and yield are influenced by the amount and distribution of precipitation, the amount of sunlight, and soil nutrient content (Snyman, 2002). Moreover, the temperature and moisture near the soil surface affect the germination and establishment of pastures (Altin *et al.*, 2011). The aboveground dry biomass of the clover and timothy mixture grown under drought

conditions was significantly lower by 36.3 to 47.2% than under optimum soil moisture and waterlogging conditions (Marcinkevičiūtė *et al.*, 2021). Conversely, the tropical grasses studied generally responded to N fertilization only under conditions of moderate to high solar radiation (Eriksen and Whitney, 1981). Several forage nutritive parameters like dry matter, CP, NDF, ADF, ADL, EE, ash, DM and OM digestibility likely to be affected by climate change (Lee *et al.*, 2013). In addition, increased temperature was shown to increase the NDF, ADF and ADL contents (Dumont *et al.*, 2015) and to decrease the CP and digestibility contents (Lee *et al.*, 2013).

Soil moisture has a decisive influence on the yield and quality of forage and other crops (Rostamza *et al.*, 2011). On the other hand, heat and drought are the two most important stressors having major impacts on crop growth and productivity (Perera *et al.*, 2019). On the other hand, soil waterlogging reduces gas exchange between the soil and the atmosphere, leading to oxygen deprivation in the rhizosphere (Cardoso *et al.*, 2013). An uneven distribution of rainfall during the growing season and droughts reduces forage grass productivity and cover, with changes in plant species composition and nutrient cycling (Bodner and Robles, 2017). The chemical composition and morphology of forage plants determines their palatability, digestibility, and nutritional value for livestock. As the climate changes, the nutritional value and digestibility of forage plants are reduced due to changes in their physiology and morphology, helping to avoid water deficit and heat stress (Grant, 2015).

In plant growth, nitrogen is the most limiting nutrient in Ethiopian soil. It is found in chlorophyll, plant proteins, and nucleic acids, and it aids in vegetative development (Yihenew G/Selassie, 2015). According to the report of Utamy *et al.* (2018), the availability of N and C in the soil after manure application might be considered adequate for subsequent cultivation of forage grasses. In addition, nitrogen in legumes derived from biological nitrogen fixation has a significant environmental advantage over synthetic nitrogen fertilizers (Sant'Anna *et al.* 2018). Conversely, the ground cover provided by forage grasses reduces runoff, soil erosion and associated basic cations which resulted improved soil organic matter and soil pH (Kumar *et al.*, 2019).

2.4 Origin and geographical distribution of Napier and desho grass

Napier grass (*Pennisetum purpureum*) occurs naturally throughout tropical Africa, particularly in east Africa (Mwendia *et al.*, 2006). It is currently used with minimal inputs and is the main fodder crop that supports the small-scale intensive dairy cattle industry in the relatively moist areas (750–2500 mm rainfall) of east Africa including at high altitudes of tropical and subtropical ecological zones (Lowe *et al.*, 2003). Among the promising improved forages in Ethiopia, Napier grass could play a significant role in providing high quality forage to the livestock production (Tessema Zewdu, 2005). According to the report of Tessema Zewdu *et al.* (2002), Napier grass is an adaptable, vigorous, highly productive species and withstands considerable periods of drought. In addition, it is palatable and categorized as medium to high quality forage (Tessema Zewdu *et al.*, 2010a).

On the other hand, desho grass (*Pennisetum pedicellatum*) is native to tropical Africa specifically in the humid highlands of Ethiopia and it was discovered as a grass species in 1991 in the Chench district of the southern region of Ethiopia (Smith, 2010). The same author reported the grass is ideal for livestock feed and can be sustainably cultivated on small plots of land. The grass can grow at altitude range of 1500–2800 m above sea level (Leta *et al.*, 2013) and performs best at altitude greater than 1700 m.a.s.l. (Danano, 2007). In addition, the grass is becoming increasingly utilized, to increase the productivity of livestock in one hand and reduce soil erosion problems on the other hand (Danano, 2007).

2.5 Effect of fertilization on the growth, yield and nutritional value of forage grasses

Several studies have been conducted on the influence of legumes on the agronomic performance of Napier grass. For example, Rahman *et al.* (2015) reported that, the DM production increased from 20 to 25 and 27 t ha⁻¹ y⁻¹ by integrating Axillaris (*Macrotyloma axillare*) and Greenleaf Desmodium (*Desmodium intortum*) respectively in Napier grass systems in central Kenya. In Sri Lanka, Seresinhe and Pathirana (2000) showed enhanced yield of grass and total output of Gliricidia (*Gliricidia sepium*) and *P. maximum* cv. Guinea mixed forage systems. Similarly, Berdahl *et al.* (2001) showed average DM yield of 8.7 and 2.71 t ha⁻¹ from grass and lucerne mixture and sole grass, respectively. Mureithi *et al.* (1995) also showed a beneficial effect to

Napier grass when grown together with *Leucaena* in coastal lowland of Kenya. They recorded increased yield of Napier grass when planted adjacent to *Leucaena* hedgerows than sole Napier grass or Napier grass growing away from *Leucaena*. This contradicts results of Mwangi (1999) who found that intercropping with *Desmodium* depressed DM yield of Napier grass but overall total yield (grass + legumes) was higher.

Alternatively, Volatsara *et al.* (2012) reported that the influence of *Desmodium* on the agronomic performance of *Brachiaria* grasses as the total DM and protein digestibility in the small intestine yields of mixture for a three years period were 9.3% and 9.4% respectively higher than those of the pure stand of *Brachiaria*. Moreover, Lobo and Acuña (2004) in Latin America and Caribbean islands reported that 18.5% higher mean dry matter yield over three consecutive years for *Brachiaria brizantha*-*Arachis pintoi* mixture compared with pure stand of *Brachiaria brizantha*. Furthermore, in Sri Lanka, Seresinhe and Pathirana (2000) showed enhanced yield of grass and total output of *Gliricidia* (*Gliricidia sepium*) and *P. maximum* cv. Guinea mixed forage systems. In addition, Berdahl *et al.* (2001) showed average DM yield of 8.7 and 2.7 t ha⁻¹ from grass/lucerne mixture and sole grass, respectively.

Fertilization is a requirement to maintaining high productivity of the grass (Tessema Zewdu *et al.*, 2002), and it performs well if intercropped with the climbing forage legumes (Alemayehu Mengistu *et al.*, 2017). In addition, Napier grass requires high levels of fertilizer and a regular water supply (Mannetje, 1992). Dry matter yields range from 20 to 80 t ha⁻¹ y⁻¹ under high fertilizer inputs (Francis, 2004). Several studies have been conducted on the influence of farmyard manure on the performance of Napier grass: Shokri (2005) reported that the organic fertilizer as either sheep manure alone or in combination with urea gave better growth performance of the Napier grass in terms of the tiller height, tiller number and leaf area index over the 6 cutting cycles of 6 weeks per cycle. The same author added treatment with 200 kg N ha⁻¹ of sheep manure gave highest dry matter yield (16 t ha⁻¹ y⁻¹) compared to control (10 t ha⁻¹ y⁻¹) in Napier grass production.

Fertilizer type had a significant effect on the height of desho grass, with inorganic fertilizer having the highest mean height and number of tillers per plant, followed by manure, and no

fertilizer having the lowest value (Biniam Mihret *et al.*, 2018). The highest dry matter yield was obtained from inorganic fertilizer, according to the same author. Fertilizer types, on the other hand, had a significant impact on the morphological characteristics, dry matter yield, and CP content of *Brachiaria Hybrid Mulato II* grass grown in Ethiopia's lowland area (Negasu Yiberkew *et al.*, 2020). The same author found that grass without fertilizer had higher NDF content, whereas inorganic fertilizer and manure had no effect on the same forage grass. Furthermore, Biniam Mihret *et al.* (2018) reported that the highest CP content was recorded under inorganic fertilization, while the lowest was recorded in the same grass without fertilizer. The same author showed neutral detergent fiber had an inverse relationship with the CP content, with the highest value recorded in the absence of fertilizer and the lowest value recorded in the presence of inorganic fertilizer.

2.6 Effects of Farmyard manure on agronomic performance and yield of forage grasses

Napier grass requires high levels of fertilizer and a regular water supply (Mannetje, 1992). Yields range from 20 to 80 t DM/ha/year under high fertilizer inputs (Francis, 2004; Skerman and Riveros, 1990). With no or inadequate fertilizers, yields are in the range of 2-10 t DM/ha/year (Bogdan, 1977). Several studies have been conducted on the influence of Farmyard manure on the performance of Napier grass: Shokri (2005) reported that the organic fertilizer as either sheep manure alone or in combination with urea gave better growth performance of the Napier grass in terms of the tiller height, tiller number and leaf area index over the 6 cutting cycles of 6 weeks per cycle. The treatment with 200 kg N/ha of sheep manure gave highest dry matter yield (16 t/ha/year) compared to control (10 t/ha/year).

A number of studies have been conducted on how organic or inorganic fertilizers influence the agronomic performance of forage crops. For instance, Frederiksen and Kategile (1980), reported that without fertilizer application, a yield of about 3 t DM/ha of *Brachiaria brizantha* on a 10-year-old field while on fertilizer application, yields were raised to about 10 t DM/ha. Moreover, Guiot (2005) reported that *Brachiaria mulato II* yielded 3.9 t DM/ha per harvest with an annual fertilization of 150 kg N and 50 kg P/ha. However, other literature stress that, under low temperature conditions *Brachiaria* grasses performs poor. For example, Ndikumana and

Leeuw (1996), reported that the optimal temperature for *Brachiaria decumbens* is 30-35°C and the low temperature depresses its growth. In addition, Villela *et al.* (2008) found that, *Brachiaria decumbens* had CP content of 11.69%, 11.08%, 9.43% and 8.93% in spring, summer, autumn and winter, respectively, showing the reduction of CP content during the winter period.

2.7 Effect of fertilizer source on soil physicochemical properties

The first step in preserving soil fertility should be to keep the organic matter content of the soil high. This can be accomplished by using proper crop husbandry practices and applying organic manure or compost in addition to mineral fertilizer (Laura and Rienke, 2004). Organic fertilizers provide nutrients to the soil over time, whereas chemical fertilizers restore soil fertility quickly (Laura and Rienke, 2004). Furthermore, Selvi *et al.* (2005) discovered that continuous application of balanced fertilization (100% N, P, and K + FYM at 10 t ha⁻¹) had no negative impact on soil physical properties; rather, it increased the soil's water holding capacity and decreased its bulk density in the long run.

Farmyard manure is an organic fertilizer that improves the chemical properties of the soil, particularly nitrogen (N), phosphorous (P), and potassium (K), allowing for increased growth and long-term production (Eghball *et al.*, 2004) resulting in maximum NPK uptake by the crop and improved soil organic carbon as well as available N, P, and K (Srivastava *et al.*, 2014) for increased growth of forage grasses. Under different fertilizer sources, soil physical properties in a degraded grazing land in Ethiopia's central rift valley did not change, but chemical properties such as soil pH, electroconductivity, total nitrogen, and P improved (Nebi Bedaso *et al.*, 2022). According to the same author, soil TN increased from 0.11 to 0.32% after cattle manure application, while pH increased from 5.9 to 7.3 after wood ash application. Moreover, planting improved forage and sowing legumes increases grassland soil carbon storage (Conant *et al.*, 2001).

Messiga *et al.* (2013), on the other hand, found that P fertilization increased soil phosphorus while N fertilization decreased soil pH, affecting the availability of exchangeable cations, but neither N nor P fertilization affected total carbon. In a long-term experiment in a wetland with different NPK fertilization treatments, land use was found to be more important in soil

acidification than fertilizers themselves (Vargová *et al.*, 2020). Organic soil carbon and available K fluctuated significantly with fertilizer rates, according to the same study, whereas total nitrogen, C:N ratio, and available P showed less dramatic changes.

CHAPTER 3. GENERAL MATERIAL AND METHODS

3.1 Description of study sites

3.1.1 Location and climate

The research was conducted at two watersheds in Upper Blue Nile basin, Ethiopia (Aba Gerima, representing midland and Guder for highland) agro-ecologies. The two locations are in the humid subtropical to moist subtropical climatic zone, between 1946 and 2885 meters above sea level.

The Aba Gerima watershed is found in the Bahir Dar Zuria district at an altitude of 1970 m.a.s.l with a total area of 426 ha. While the Guder watershed is found in Fagta Lekoma district at an elevation of 2577 m.a.s.l. (Fig. 3.1) with total area of 397.5 ha. Based on long term rainfall records (1982–2019) from nearby meteorological stations, the mean annual rainfall at Aba Gerima and Guder was 1343 mm and 2454 mm, respectively (Mulatu Liyew *et al.*, 2019).

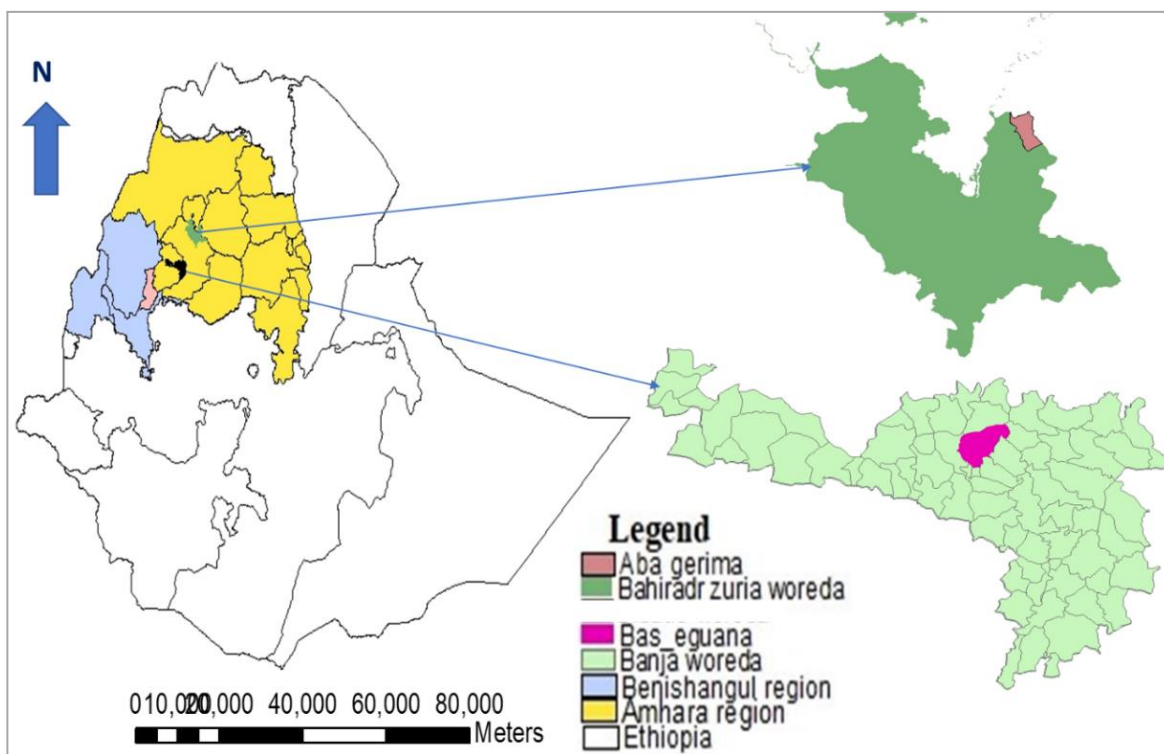


Figure 3.1 Location map of study sites

Table 3.1 Climatic features of the two watersheds in the Upper Blue Nile basin Ethiopia

Features	Aba Gerima	Guder
Location	37°29'35"E–37°30'52"E and 11°38'51"N–11°40'34"N	36°54'09"E–36°55'55"E and 10°59'34"N–11°01'01"N
Elevation (m a.s.l)	1946–2234	2555–2885
Mean annual rainfall (mm)	1343	2454
Mean daily temperature (°C)	23.5	19.5
Agro-ecological zone	Midland (Weynadega)	Highland (Dega)
Rainfall pattern	Unimodal	Unimodal
Major soils	Luvisols, Leptosols	Acrisols, Luvisols
Major land use types	Cropland, grazing land, degraded bushland	Cropland, grazing land, degraded bushland
Farming system	Mixed crop–livestock	Mixed crop–livestock
Major crops	Finger millet, tef, maize, and khat	Tef, barley, wheat, and potato
Major livestock types	Cattle, sheep, goat, donkeys	Cattle, sheep, horses

Source: Kindye Ebabu *et al.*, 2020

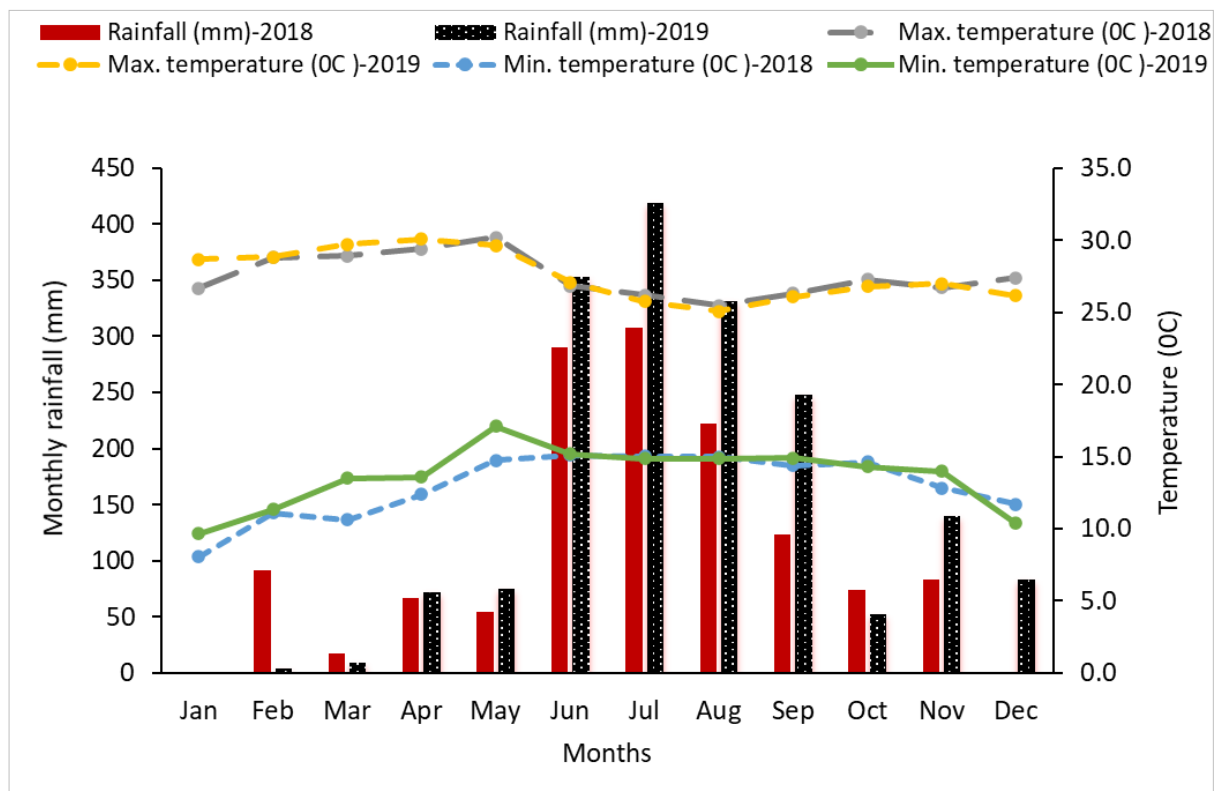


Figure 3.2 Two experimental years average monthly rainfall and temperature distribution at Aba Gerima watershed (Source: Bahir Dar meteorological station)

The mean annual rainfall at Aba Gerima was 1330 and 1786 mm, while at Guder the value was 2438 and 2302 mm in 2018 and 2019 production years, respectively from nearby Bahir Dar meteorological station. The annual mean minimum and maximum temperatures were from 13.0 and 27.5 °C for the year 2018, while for 2019 the values were 13.6 and 27.6 °C at Aba Gerima (Fig. 3.2). Where as in 2018, the average minimum and maximum temperatures were 10.2 and 25.0 °C, and 10.9 and 25.3 °C in 2019 at Guder watershed (Fig. 3.3).

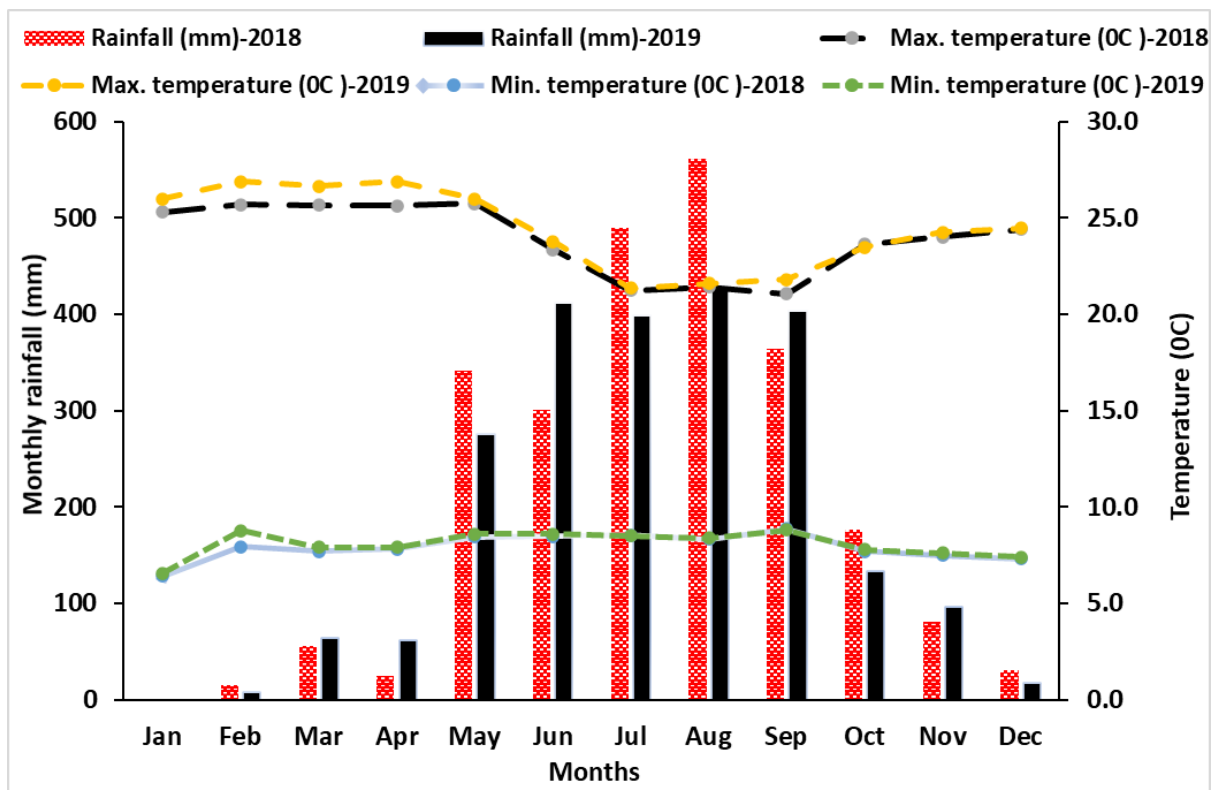


Figure 3.3 Two experimental years average monthly rainfall and temperature distribution at Guder watershed (Source: Bahir Dar meteorological station)

3.1.2 Major soil types

The major soil types (as classified by the FAO) are Acrisols the most common at Guder, followed by Luvisols, Leptosols, and vertisols, while Leptosols are the most common at Aba Gerima (Mekonnen Getahun, 2016). Acrisols are distinguished by the accumulation of low activity clay in the subsoil, whereas luvisols are distinguished by very deep, well-drained soils with clay accumulation (FAO, 2006). According to the ratings, the soils are generally low in

available phosphorus content in both watersheds, while soil organic matter and total nitrogen content are low in Aba Gerima and Guder according to the ratings of (Landon, 2014). The pH of the soil at Guder was 5.2, while the value at Aba Gerima was 5.5 which could be classified as strongly acidic to moderately acidic, respectively for the two watersheds.

3.1.3 Land use and farming system

The landscapes in the two locations are fragmented as a result of decades of diverse traditional land use practices. Cultivated fields, grazing lands, and degraded bushlands are the three main land use types. A greater proportion of cultivated lands (31- 61%) than non-cultivated areas exists at all sites (grazing lands and degraded bushlands) (Mulatu Liyew Berihun *et al.*, 2019). The main livelihoods for farmers in the watersheds are mixed crop cultivation and livestock rearing. In Aba Gerima watershed, finger millet (*Eleusine coracana*), maize (*Zea mays*), and tef (*Eragrostis tef*) are the major crops grown, while in Guder tef (*Eragrostis tef*), barley (*Hordeum vulgare*), wheat (*Triticum aestivum*), and potato (*Solanum tuberosum*) are the most important crops grown in the watershed (Kindye Ebabu *et al.*, 2019). The main livestock species reared by most farmers are cattle (*Bos primigenius*), sheep (*Ovis aries*), goats (*Capra hircus*), and donkeys (*Equus africanus*) at Aba Gerima, while cattle (*Bos primigenius*), sheep (*Ovis aries*), and horses (*Equus caballus*) are common livestock species at Guder (Kindye Ebabu *et al.*, 2019). Quality and quantity feed production, on the other hand, is one strategy in the country's livestock master plan to increase total cattle milk production through improvements in family cow dairy production and specialized dairy production units. Because crossbred cattle are emerging in the area, they require high quality and quantity of feed throughout the year for better production.

3.2 Experimental materials and treatments

In the field experiment, two separate plot level experiments were conducted for two consecutive years (2018 and 2019). In the first experiment, cultivated land was used for forage grass agronomic and nutritional study. The parameters measured were plant growth characteristics, yield, nutritional value and soil physicochemical properties of Napier and desho grass in midland and highland agro-ecologies. The treatments used were Napier or desho grass alone [control], Napier or desho with green leaf Desmodium, Napier or desho with FYM, and Napier

or desho combined with green leaf Desmodium and FYM. Whereas, for the second experiment grazing land FYM and silver leaf Desmodium was used as fertilizer sources and Napier and desho grasses as enrichment planting in midland agroecology (Aba Gerima) watershed only. Natural pasture plots were treated with: Napier grass (*Pennisetum purpureum*) or desho grass (*Pennisetum pedicellatum*), Napier or desho + FYM, Napier or desho + silver leaf Desmodium, and Napier or desho + FYM + silver leaf Desmodium; untreated plots (natural pasture alone) were used as controls.

3.3 Land preparation and Soil sampling

The experimental land was ploughed three times at the onset of the main rainy seasons before planting in the first experiment, while in grazing land (second experiment) to minimize soil disturbance, holes for planting forage grasses were made at the beginning of the main rainy season. Before applying treatments (farmyard manure and Desmodium) in the first year, a composite soil sample was collected at 20 cm depth using soil auger per treatment for each watershed in both experiments. Furthermore, at the end of the experiment in the second year, soil samples were collected in the same way above from each plot and air dried in a shed for physicochemical analysis.

3.4 Data collection and chemical analysis

The growth characteristics and yield data were taken at appropriate stage of growth for each experiment. Representative plant samples from each experiment were taken from each plot and drying in an oven at 65 °C for 72 hours until constant weight was attained for subsequent chemical analysis. Respective of each experiment's objective both soil and plant analyzed using standard procedures (Table 3.2). Soil organic carbon, total nitrogen, pH, from the soil and nitrogen, ash and volatile fatty acid from the forage sample were analyzed at Tottori University laboratory while ether extract, gross energy, and in vitro gas fermentation were done at Shimane University nutrition laboratory, Japan. However, forage fiber fractions (NDF, ADF and ADL) were analyzed at Bahir Dar University Nutrition laboratory.

Table 3.2 Selected parameters analyzed for soil and forage samples and the standard methods used for analysis.

Type of sample	Parameters analyzed	Method of analysis
Forage	N	CN corder (Macro Corder JM1000CN, J-Science Lab, Kyoto, Japan)
	Ash	Burning with muffle furnace (AOAC, 1990)
	NDF, ADF, ADL	Van Soest <i>et al.</i> , 1991
	EE	Gravimetical method (AOAC, 1990)
	IVOMD	Syringe method (Menke and Steingass, 1988)
	VFA	Gas chromatography (Menke and Steingass, 1988)
Soil	SOC and TN	CN corder
	Bulk density	Core sampler method, oven-dried at 105°C for 24 h
	Soil pH (H ₂ O) 1:2.5	Potentiometric pH meter (Peech, 1965)
	P _{av}	Sodium bicarbonate method (Olsen, 1954)

ADF: acid detergent fiber, ADL: acid detergent lignin, EE: ether extract, NDF: neutral detergent fiber, P_{av}: available phosphorous, SOC: Soil organic carbon, TN: total nitrogen, VFA: volatile fatty acid.

CHAPTER 4. EFFECTS OF FARMYARD MANURE AND DESMODIUM INTERCROPPING ON FORAGE GRASS GROWTH, YIELD, AND ITS EFFECT ON SOIL PROPERTIES IN DIFFERENT AGRO-ECOLOGIES OF UPPER BLUE NILE BASIN, ETHIOPIA

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Abstract

Enhancing forage production through organic fertilization is an important option for smallholder farmers. In north-western Ethiopia, a field experiment was conducted to assess the effects of farmyard manure (FYM) and *Desmodium intortum* (green leaf Desmodium) intercropping on the morphological characteristics, dry matter yield, and crude protein yield of Napier and desho grass, as well as its effects on soil physicochemical properties. The experiment was carried out in three replications using randomized complete block design with factorial arrangements at the Aba Gerima and Guder watersheds, which represent midland and highland agro-ecologies, respectively. The treatments used were Napier or desho grass alone [control], Napier or desho with green leaf Desmodium, Napier or desho with FYM, and Napier or desho combined with green leaf Desmodium and FYM. The results showed that fertilizer treatments had positive influence on morphological characteristics in both watersheds. The dry

matter yield and crude protein yield were higher ($p < 0.001$) with FYM as well as FYM combined with green leaf Desmodium (9.1 to 9.6 t ha⁻¹ and 866.7 to 792.4 kg ha⁻¹) at Aba Gerima and (7.0 to 7.1 t ha⁻¹ and 795.3 to 510.5 kg ha⁻¹) at Guder, respectively. The fertilizer treatments, i.e., FYM and combined use of FYM and green leaf Desmodium groups, showed soil organic carbon (18.4% and 20.5%) and available phosphorous (16.3% and 23.0%) content increments over the control at the Aba Gerima watershed. The findings suggested that applying FYM and combining FYM and green leaf Desmodium improved forage grass growth and yield by maintaining soil health in the dryland areas of Ethiopia's Upper Blue Nile basin.

Key words: *Desmodium intortum*; Dryland; Dry matter yield; Farmyard manure; Fertilizer treatments; Forage grasses

4.1 Introduction

In the tropics, livestock production is an important economic activity that produces both food and non-food commodities. The Ethiopian livestock sub-sector contributes 10% to total export earnings, primarily through the export of ruminant animals (FAO, 2019). Furthermore, the sector accounts for 45% of agricultural GDP, including economic values and non-marketed services such as draft power and manure (FAO, 2019) and 37% to 87% of household income (Behnke and Metaferia, 2013). Despite its significant contribution, livestock productivity in Ethiopia is lower than the African average, owing primarily to feed shortages both in quality and quantity (Ahmed Hassen *et al.*, 2010; Bizelew Gelayenew *et al.*, 2020). To exploit the potential of livestock, use of improved forages is one of the strategies in Ethiopia small holder farmers (Adugna Tolera *et al.*, 2012).

The major feed resources in Ethiopia are grazing pasture, crop residue, improved feed, hay, by-products, and others, which contribute 54.5%, 31.1%, 0.57%, 7.4%, 2.0%, and 4.4% of the feed demand, respectively (CSA, 2021). However, the area of grazing land is decreasing from time to time due to poor management and encroachment of crop cultivation (FAO, 2004). This decrease is accompanied by an increase in the role of crop residues, which are generally of low nutritional value (Zerbini and Thomas, 2003). Thus, the role of improved forage grass and legume species with high biomass yield and nutritional value is very important (Adugna Tolera *et al.*, 2012). Nevertheless, its contribution to livestock feed resources was less than 1% (CSA,

2021). According to Lemma *et al.* (2010), only 0.15% of smallholder farmers practice on-farm improved forage production. Land shortage, low access and high cost of seed and planting materials, and lack of awareness of their importance and production are the major impediments to low practice of improved forage production by smallholder farmers (Alemayehu Abebe *et al.*, 2018; Shimelis Mengistu *et al.*, 2021).

Several grass and legume forage crops have been identified and introduced into Ethiopian farmer fields over the last five decades. Among the adapted forage grasses are Napier grass (*Pennisetum purpureum*) and desho grass (*Pennisetum pedicellatum*), most commonly used by livestock producers in northwestern Ethiopia (Tessema Zewdu *et al.*, 2002; Bimrew Asmare *et al.*, 2017). In addition, the legume *Desmodium intortum* has been introduced and is being grown on various land uses as a mixed pasture, with multiple advantages over the monoculture of forage grasses. Desmodium's common benefits included forage production, nitrogen fixation, and soil erosion control (Alemayehu Mengistu *et al.*, 2017). The growth, yield, and nutritive value of forage crops are a function of various factors such as soil fertility, agro-ecology, fertilizer type, land preparation, and management. The dominating soils in the experimental locations are luvisols in midland agro-ecologies and acrisols in highland agro-ecologies (Kindye Ebabu *et al.*, 2020), which are ideal for a wide range of plant species. In a survey conducted by Bimrew Asmare *et al.* (2016) in north western and southern Ethiopia reported that fertilization practices for forages are not uniform in terms of application or fertilizer form. The amount of chemical fertilizer applied to crop production is low in Ethiopia due to its high cost for resource-poor smallholder farmers (Kefyalew Endale, 2016). Furthermore, inorganic fertilizers do not last long in the soil and must be reapplied frequently. Farmyard manure (FYM) is an organic fertilizer that improves the chemical properties of the soil, specifically nitrogen (N), phosphorous (P), and potassium (K), allowing for increased growth and sustainable production (Eghball *et al.*, 2004).

Several researchers reported that application of inorganic fertilizer and FYM improved forage morphological characteristics, biomass yield, nutritive value, and soil physicochemical properties (Tessema Zewdu *et al.*, 2002; Utamy *et al.*, 2018; Maleko *et al.*, 2019; Ma *et al.*, 2020). However, there is limited research on the extent to which integration of forage grasses

with FYM and legumes like *Desmodium intortum* as fertilizer treatments affects the growth and yield of forage grasses as well as its association with the factors considered and parameters measured. Moreover, there is limited information on soil physicochemical properties under different climatic conditions for longer production times in the study areas. Therefore, the study was carried out to assess the effects of FYM and *Desmodium intortum* on the growth characteristics, yield, and soil physicochemical properties of Napier and desho grass in different agro-ecologies for sustainable and environmentally friendly forage production in the Upper Blue Nile basin, Ethiopia.

4.2 Materials and Methods

4.2.1 Description of study areas

The field experiment was undertaken in rain-fed conditions from May 2018 to December 2019 in two selected watersheds in the Amhara Region, Upper Blue Nile basin, Ethiopia: Aba Gerima and Guder (Bas-eguana), representing midland and highland agro-ecologies, respectively (Fig.3.1).

The Aba Gerima watershed is found in the Bahir Dar Zuria district and lies within 37°29'35"E–37°30'52"E and 11°38'51"N–11°40'34"N with an altitude of 1970 meters above sea level and a total area of 426 ha. The experimental years' rainfall and temperature were collected from the northwestern Bahir Dar metrological station. The total rainfall at Aba Gerima watershed in the 2018 and 2019 cropping seasons was 1330 and 1786 mm, respectively. The annual mean minimum and maximum temperatures varied from 13.0 to 27.5 °C for the year 2018, while for 2019 the value was 13.6 to 27.6 °C (Fig.3.2). Furthermore, the mean annual rainfall at nearby meteorological stations was 1343 mm from 1999 to 2015, with mean annual minimum and maximum temperatures ranging from 13 to 27 °C (Kindye Ebabu *et al.*, 2019). The main livelihoods for farmers in the watershed are mixed crop cultivation and livestock rearing. The main livestock species reared by most farmers are cattle, sheep, goats, and donkeys. In the watershed, finger millet, maize, and tef are the major crops grown (Kindye Ebabu *et al.*, 2019).

The Guder watershed is located at an elevation of 2577 m above sea level within 36°54'09"E–36°55'55"E and 10°59'34"N–11°01'01"N in the district of Fagta Lekoma. The pattern of

rainfall is similar to that in Aba Gerima, and the values were 2438 and 2302 mm for the 2018 and 2019 cropping seasons, respectively. In 2018, the average minimum and maximum temperatures ranged between 10.2 and 25.0 °C, and 10.9 and 25.3 °C in 2019 (Fig.3.3). Among the livestock species reared in the watershed are cattle, sheep, and horses. Tef, barley, wheat, and potato are the most important crops grown in the watershed (Kindye Ebabu *et al.*, 2019).

4.2.2 Treatments and experimental design

The entire experimental land was 630 m² and comprised a total of 24 plots with three blocks (replications), each of which comprised eight plots (4 m x 3 m each) with a 1-m buffer zone between plots (Appendix Fig. 4.1). For two years, the experiment was conducted with a randomized complete block design in factorial arrangements (two forage grasses by four fertilizer treatments) and three replications. The forage grasses (Napier grass, *Pennisetum purpureum*, acc. 16791; and desho grass, *Pennisetum pedicellatum*, Kulumsa DZF-592) were collected from a nearby research center (Andassa Livestock Research Center), which were well adapted to the area and recommended for wider evaluation for their good biomass yield with better nutritive value (Tessema Zewdu, 2005; Wondmeneh *et al.*, 2016). The legume green leaf Desmodium was brought from Debre Zeit Agricultural Research Center with a 90% germination percentage. The treatments used were Napier grass alone, desho grass alone, Napier grass + green leaf Desmodium, desho grass + green leaf Desmodium, Napier grass + FYM, desho grass + FYM, Napier grass + green leaf Desmodium + FYM and desho grass + green leaf Desmodium + FYM, a total of eight treatment combinations in two watersheds for two consecutive years.

4.2.3 Sampling and analysis of soil

Before applying treatments (farmyard manure and *Desmodium intortum*) in May 2018 (the first year), one-kg soil samples were collected from each plot with a soil auger at 20 cm depth, and a composite sample was collected for each watershed per treatment. Furthermore, at the end of the experiment in December 2019 (the second year), soil samples were collected from each plot in the same manner as described above. In a shed, both soil samples were air dried and crushed with a mortar before being passed through a 2 mm sieve for physicochemical analysis. The soil samples were mixed 1:2.5 with water and mechanically shaken for 1 h until a uniform solution

was formed for the pH and electrical conductivity (EC) analyses. After calibration with standard solutions, the sample suspensions were measured with a pH and conductivity meter. Five hundred milligram of soil was taken for total nitrogen (TN) and soil organic carbon (SOC) analysis, and TN and SOC were determined using an automatic carbon/nitrogen analyzer (JM1000CN; J-Science Lab Co., Ltd., Kyoto, Japan). The method of Bray and Kurtz (1945) was used to calculate available phosphorus (P_{av}).

Table 4.1 Soil properties of experimental plots prior to treatment application (Desmodium and farmyard manure) in 2018

Soil properties	Experimental sites		Farmyard manure properties
	Aba Gerima	Guder	
SOC (%)	1.29	3.98	17.5
TN (%)	0.13	0.36	1.5
P _{av} (mg kg ⁻¹)	8.4	14.9	32.8
ECEC (cmol _c kg ⁻¹)	13.0	6.1	82.0
EC (mSm ⁻¹)	6.8	4.0	0.34
pH	5.5	5.2	7.4
Soil texture			
Sand (%)	12.9	10.7	-
Silt (%)	19.6	30.6	-
Clay (%)	67.5	58.7	-
Soil textural class	Clay	clay	-

EC: electric conductivity; ECEC: effective cation exchange; P_{av}: available phosphorous; pH: soil reaction; SOC: soil organic carbon; TN: total nitrogen

Soil samples were identified before the experiment began, and the proportions of clay, silt, and sand content were classified as 67.5%, 19.6%, and 12.9% at Aba Gerima and 58.7%, 30.6%, and 10.7% at Guder, respectively, both of which were classed as clay in texture (EthioSIS, 2013). In addition, the pH at Guder was 5.1–5.3 (strongly acidic) and at Aba Gerima, 5.3–5.8 (moderately acidic) before the application of treatments (Table 1). The dominant soils in the experimental areas are classified as luvisols at Aba Gerima and acrisols at Guder (Kindye Ebabu *et al.*, 2020).

4.2.4 Land preparation, planting, and management

The experimental land was ploughed three times at the onset of the rainy seasons before planting. The FYM (cattle manure with small amount of roughage feed residues and urine) was collected from Bahir Dar University, Zenzelma campus. The FYM was applied at the rate of 12 t ha^{-1} (Tessema Zewdu *et al.*, 2002; Desalegn Ayichew, 2017) for Napier and other similar grasses with growth characteristics in dry matter basis. In the field FYM was first crushed and mixed with the soil manually by disturbing the plot for ease of decomposition one month before planting of forage grasses. The forage grasses were planted by selecting healthy root splits. Desho grass was spaced 50 cm between both inter and intra rows (Tekalegn Yirgu *et al.*, 2017). While, Napier grass was planted 1m inter-rows and 50 cm intra-row spacing (Appendix Fig. 4.1). When Napier and desho grasses reach at the age of one month, the plot was first manually weeded and harrowed and drilled green leaf Desmodium seed between two forage grass rows with 5 kg ha^{-1} seed rate; at 1 cm soil depth kept the seed and covered slightly for ease of germination (Lice and Vin, 2016). Weed control and harrowing were done frequently for each year manually as necessary to ensure weed-free plots.

4.2.5 Data collection and measurements

Plant height at cutting (PH), leaf length (LL), leaf width (LW), and number of tillers per plant (NTPP) were all measured on five randomly chosen plants from the middle rows (Zewdu *et al.*, 2003a). For good biomass yield and nutritional value, Napier grass was harvested when it reached 1 m in height (Tessema Zewdu *et al.*, 2002), while desho grass was harvested at a height of 50–60 cm in the plot for similar properties (Bereket Dindamo *et al.*, 2016) (Appendix Fig. 4.2). By removing the boundary rows from the plot, harvesting was done by hand with a sickle, leaving a stubble height of roughly 5–10 cm above the ground (Lounglawan *et al.*, 2014). Sub-samples were taken from each plot by weighing with a sensitive balance (0.001 g) and drying in an oven at 65°C for 72 h until constant weight was attained to calculate dry matter (DM) percentage and subsequent chemical analysis.

The dry matter yield (DMY) was computed by multiplying the dry matter percentage with the fresh biomass taken from the sampling area and converting the result to t ha^{-1} . Furthermore, the leaf-to-stem ratio (LSR) was calculated by harvesting leaves and stems separately from center

rows in a plot with a sampling area of 1 m², then partitioning the harvested sample into leaf and stem components and drying the sample for DM yield estimation, as indicated above. However, root variables like root length (RL) and number of roots per plant (NRPP) were measured for each treatment with its replication once in the second year of harvest by careful excavation and pulling with soil to avoid root damage and losses. Then the excavated roots with soil were transferred from the field to the laboratory in a plastic container, placed in a bucket of water, and washed gently with running tap water to clean off the remaining soil and other debris (Appendix Fig. 4.3). Finally, the shoots and roots were carefully separated using scissors and dried in a 65 °C oven for 72 h until they attained a steady weight for DM determination. For each treatment, a shoot-to-root ratio (S: R) was computed based on shoot and root biomass yield (RBY).

4.2.6 Statistical analysis

Data from the evaluation of improved fodder grasses (morphological traits, yield, and soil physicochemical parameters) were pooled across the year and evaluated using two-way ANOVA for each watershed/location using Statistical Analysis Software SAS_JMP13 (SAS, 2016). However, below ground root characteristics were one-year data and analyzed following the same procedure as above. Tukey's honest significance test was used to indicate significant differences between treatment means at $p < 0.05$. The statistical model for the analysis of data was as follows:

$$Y_{ijk} = \mu + S_i + F_j + A_k + (S \cdot F)_{ij} + (S \cdot A)_{ik} + (F \cdot A)_{jk} + (S \cdot F \cdot A)_{ijk} + e_{ijkm}$$

where:

Y_{ijk} = all dependent variables (morphological characteristics yield and soil physicochemical properties); μ = overall mean; S_i = effect of forage grasses (i = Napier and desho grass); F_j = effect of fertilizer treatments (j = control, FYM, desmodium, and combination of FYM and desmodium); A_k = effect of years (k = 2018 and 2019); $(S \cdot F)_{ij}$ = interaction of forage grasses and fertilizer treatments; $(S \cdot A)_{ik}$ = interaction of forage grasses and year; $(F \cdot A)_{jk}$ = interaction of fertilizer treatments and year; $(S \cdot F \cdot A)_{ijk}$ = interaction of forage grasses, fertilizer treatments and year; e_{ijkm} = random error.

4.3 Results

4.3.1 Fertilizer treatments effects on soil physicochemical properties

The soil physicochemical properties after treatment application are shown in Figure 4.1 and 4.2 for Aba Gerima and Guder watersheds, respectively. Soil physical properties like bulk density (BD) varied between treatment groups in both watersheds. Both Napier and desho grass planted with FYM and combined use of Desmodium and FYM showed significantly lower ($p<0.05$) BD compared to two grasses alone and with Desmodium in both watersheds. However, there were no significant differences in BD among forage grass alone and with Desmodium treatments. In contrast, soil moisture levels improved by 22.9% and 24.7% in December for desho grass and 8.8% and 6.2% for Napier grass at Aba Gerima, respectively, with FYM and combined use of FYM and Desmodium. Moreover, in Guder, for similar fertilizer treatments, desho recorded 15.9% and 14.1%, while 21.0% and 5.8% for Napier grass (Appendix Fig. 4.4). At Aba Gerima, the soil chemical properties SOC and TN differed significantly ($p<0.01$) from the control and Desmodium, but not at Guder.

In Aba Gerima watershed, most soil chemical properties (SOC, TN and P_{av}) showed significantly higher concentration in desho grass with FYM and combined use of Desmodium and FYM compared to forage grass alone and with Desmodium. Furthermore, P_{av} was higher in forage grasses with FYM and combined use of Desmodium and FYM treatment groups compared with forage grasses alone at Guder watershed. Among forage grasses with FYM at Aba Gerima, compared to grass alone, SOC (18.4% and 20.5%), TN (15.4%) and P_{av} (16.3% and 23.0%) were higher with FYM and combined use of *Desmodium* and FYM treatments, respectively. Despite the lack of significant differences in most soil chemical properties within treatments relative to forage grass alone at Guder, P_{av} increased by 9.4% in FYM and 17% in combined use of FYM and Desmodium. On the other hand, the pH content of treatment groups when compared before the application of treatments, the improvement was greater; 0.4 with FYM and 0.5 with the combined use of FYM and Desmodium in both forage grasses (Fig.4.1 and 4.2).

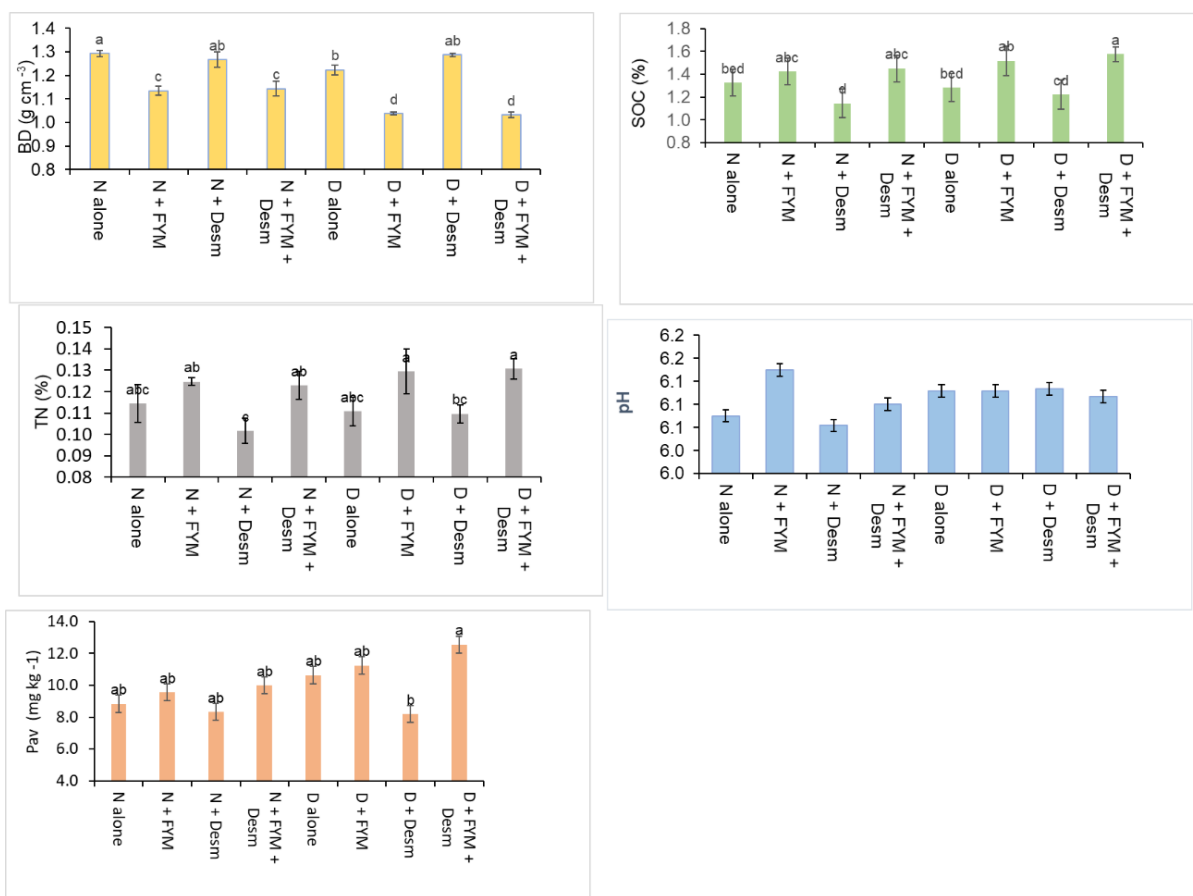


Figure 4.1 Soil physicochemical properties under various fertilizer treatments after treatment application at Aba Gerima watershed

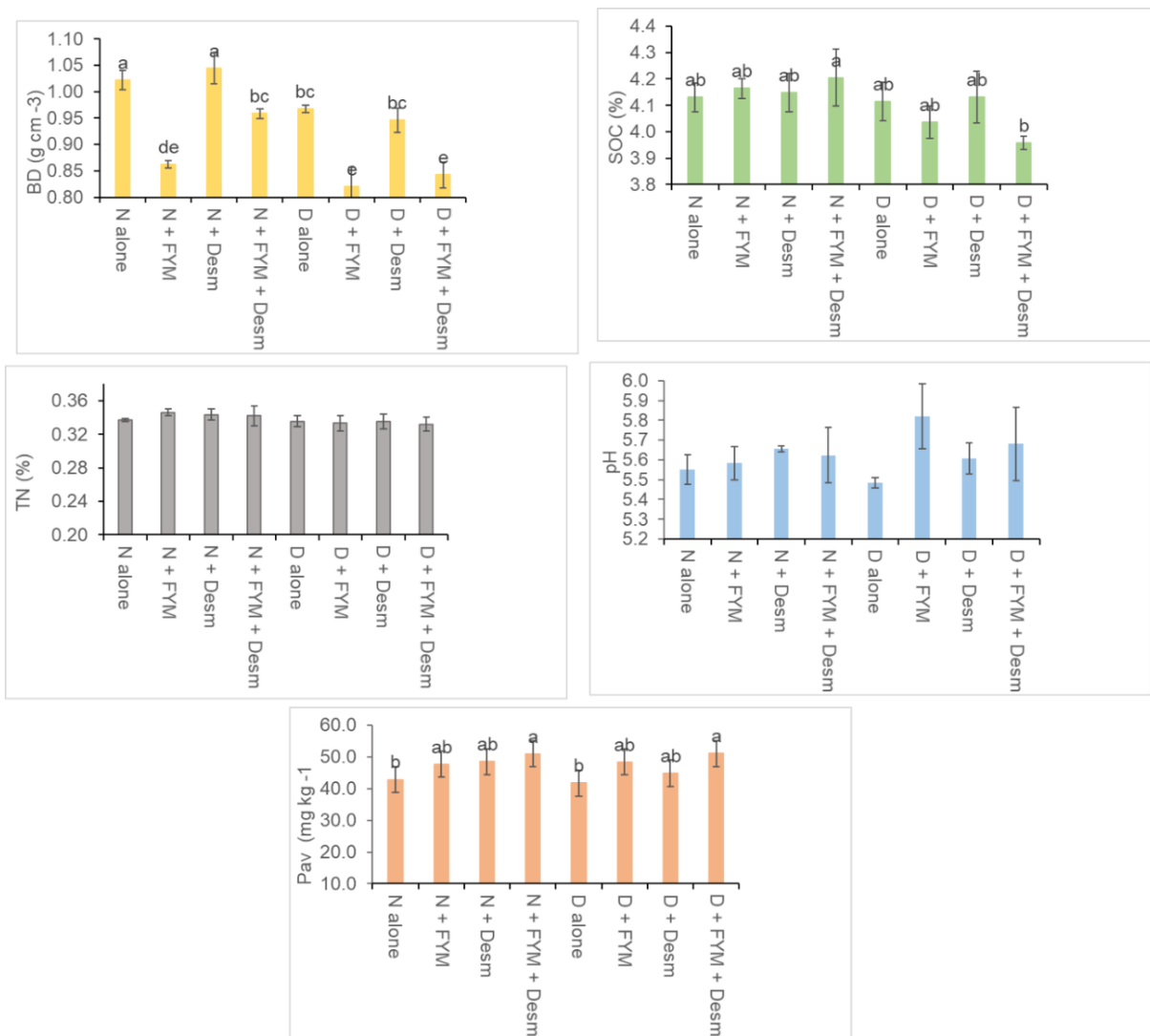


Figure 4.2 Effects of various fertilizer treatments on soil physicochemical properties after treatment application at Guder watershed

BD: bulk density; D: desho grass; Desm: Desmodium intortum; FYM: farmyard manure; SOC: soil organic carbon; TN: total nitrogen; Pav: available phosphorous; and pH: soil reaction.

4.3.2 Effects of fertilizer treatments on the morphology and yield of forage grasses in the Aba Gerima watershed

The effects of morphological characteristics and yield of two forage grasses under four fertilizer treatments are shown in Table 4.2. for Aba Gerima watersheds. Plant height at cutting, LL, LW, LSR, and yield all differed significantly ($P < 0.001$) between Napier and desho grass in the Aba Gerima watershed. Similarly, when compared to control and Desmodium with forage grasses, most measured morphological characteristics (PH, LL, and NTPP) were significantly improved

in both FYM and the combined use of FYM and Desmodium. We found the DMY was increased by 2.2%, 39.7%, and 34.8% in the second year for forage grasses treated with Desmodium, FYM, and a combination of FYM and Desmodium, respectively, compared to the control at Aba Gerima.

Table 4.2 Effects of fertilizer treatments and production years on the morphology and yield of forage grasses in the Aba Gerima watershed

	PH	LL	LW	NTPP	LSR	DMY	CP	CPY
Variables	cm			plant ⁻¹		t ha ⁻¹	g kg ⁻¹	kg ha ⁻¹
Forage grasses								
Napier grass	101.1 ^a	73.9 ^a	2.8 ^a	35.3 ^b	2.3 ^a	9.2 ^a	91.3 ^a	887.8 ^a
Desho grass	50.7 ^b	29.1 ^b	1.5 ^b	96.9 ^a	1.6 ^b	6.1 ^b	69.4 ^b	468.4 ^b
SL	***	***	***	***	***	***	***	***
SEM	1.12	0.64	0.03	2.54	0.04	0.18	2.13	25.71
Fertilizer treatments								
Control	71.4 ^b	48.9 ^c	2.1	56.6 ^c	1.9	5.9 ^b	85.0	536.7 ^b
Desmodium	72.1 ^b	49.6 ^{bc}	2.1	59.7 ^{bc}	2.0	6.1 ^b	78.6	604.8 ^b
FYM	73.5 ^a	53.0 ^{ab}	2.2	72.8 ^{ab}	2.0	9.6 ^a	78.2	762.2 ^a
Desmodium& FYM	81.5 ^a	54.6 ^a	2.2	75.4 ^a	2.0	9.1 ^a	79.5	808.8 ^a
SL	***	***	*	**	ns	***	ns	***
SEM	1.59	0.89	0.04	3.59	0.08	0.26	3.01	36.37
Year								
2018	74.8	50.6	2.1 ^b	36.3 ^b	1.9 ^b	3.9 ^b	81.1	321.6 ^b
2019	77.1	52.3	2.2 ^a	95.9 ^a	2.0 ^a	11.5 ^a	79.6	1034.7 ^a
SL	ns	ns	**	***	*	***	ns	***
SEM	1.12	0.64	0.03	2.54	0.04	0.18	2.13	25.71
Overall mean	75.9	51.5	2.2	66.1	1.9	7.7	80.3	678.1
CV (%)	7.3	6.1	6.8	18.8	11.5	11.7	10.4	18.6
Interaction								
F*FS	ns	ns	ns	ns	ns	ns	ns	*
F*Y	ns	ns	ns	ns	ns	***	ns	*
FS*Y	***	ns	***	***	***	***	ns	***

Mean PH was higher with FYM as well as Desmodium (81.5 cm) and FYM (73.5 cm) as compared to control (71.4 cm) and with Desmodium alone (72.1 cm). Moreover, NTPP followed the same trend, with 75.4 in the combined use of FYM and Desmodium and 72.8 in FYM treatment. All growth parameters were significantly higher for Napier grass than for desho grass, except for NTPP, for which the value for desho grass was significantly higher (96.9

versus 35.3). Other growth and yield parameters showed significant ($P<0.001$) variation in the forage grass year interaction, with the exception of LL and crude protein (CP) content. The dry matter and crude protein yield (CPY) followed similar trends with growth characteristics, and the value was higher in FYM as well as in the combined use of FYM and *Desmodium* than in control and Desmodium treatments at the Aba Gerima watershed for both Napier and desho grass (Appendix Table 4.4).

4.3.3 Effects of fertilizer treatments on the morphology and yield of forage grasses in the Guder watershed

The effects of fertilizer treatments and production year of two forage grasses on growth properties and yield are presented in Table 4.3 for the Guder watershed. The height of Napier grass was longer than that of desho grass, while NTPP was higher in desho grass than in Napier grass. Moreover, similar to Aba Gerima, all growth properties showed higher value in 2019 than in the 2018 production year.

In terms of DMY, CPY and CP content, the tendency was similar with Aba Gerima in that forage grasses with FYM and combined use of FYM and Desmodium significantly varied ($P<0.001$) as compared to control for both Napier and desho grass (Appendix Table 4.5). In addition, there was significant variation between production years in forage grasses and fertilizer treatments, while the CP content of forage grasses did not vary within years. The interactions between the forage species and fertilizer treatments did not vary in most growth and yield parameters, though some change was observed between forage species and year interaction in all growth and yield parameters.

Table 4.3 Effects of fertilizer treatments and years on morphological characteristics and yield of forage grasses in the Guder watershed

	PH	LL	LW	NTPP	LSR	DMY	CP	CPY
Variables	cm			plant ⁻¹		t ha ⁻¹	g kg ⁻¹	kg ha ⁻¹
<i>Forage grasses</i>								
Napier grass	88.2 ^a	70.7 ^a	2.2 ^a	30.7 ^b	2.3 ^a	5.6	131.8 ^a	795.3
Desho grass	42.7 ^b	24.5 ^b	1.4 ^b	97.3 ^a	1.9 ^b	6.0	98.2 ^b	510.5
SL	***	***	***	***	***	ns	***	***
SEM	1.06	0.67	0.03	2.51	0.04	0.18	2.04	28.30
<i>Fertilizer treatments</i>								
Control	61.3 ^b	45.9 ^b	1.7 ^b	58.3 ^b	2.0	4.4 ^b	111.9 ^{ab}	454.2 ^b
Desmodium	62.1 ^b	45.6 ^b	1.7 ^b	57.7 ^b	2.1	4.7 ^b	108.8 ^b	498.2 ^b
FYM	70.4 ^a	50.2 ^a	1.9 ^a	67.4 ^{ab}	2.1	7.0 ^a	121.7 ^a	866.7 ^a
Desmodium& FYM	67.9 ^a	48.5 ^{ab}	1.8 ^{ab}	72.4 ^a	2.1	7.1 ^a	117.7 ^{ab}	792.4 ^a
SL	**	**	*	*	ns	***	*	***
SEM	1.50	0.95	0.04	3.55	0.06	0.26	2.88	40.02
<i>Year</i>								
2018	55.5 ^b	43.2 ^b	1.6 ^b	28.4 ^b	2.0 ^b	0.7 ^b	114.3	80.7
2019	75.3 ^a	51.9 ^a	2.0 ^a	99.6 ^a	2.2 ^a	10.9 ^a	115.8	1225.1
SL	***	***	***	***	**	***	ns	***
SEM	1.06	0.67	0.03	2.51	0.04	0.18	2.04	28.30
Overall mean	65.4	47.6	1.8	64.0	2.1	5.8	115.0	652.9
CV (%)	7.9	6.9	7.9	19.2	10.1	15.3	8.7	21.2
<i>Interaction</i>								
F*FS	*	ns	ns	ns	ns	*	ns	ns
F*Y	**	ns	ns	ns	ns	*	***	***
FS*Y	***	***	ns	***	***	***	*	***

The values within a column that bear the same letter are not statistically different ($p < 0.05$); FS: forage species; Y: year; F: fertilizer treatments. DMY: dry matter yield; CP: crude protein; CPY: crude protein yield; PH: plant height; LL: leaf length; LW: leaf width; NTPP: number of tillers per plant; LSR: leaf-to-stem ratio.

4.3.4 Forage grass root biomass yield and shoot-to-root ratio

The effects of fertilizer treatments on Napier and desho grass root characteristics are shown in Table 4.4 for Aba Gerima and Table 4.5 for Guder watershed. Fertilizer treatments had a significant ($p < 0.05$) effect on RBY but not on RL, S: R, root soil organic carbon (RSOC), or

root total nitrogen (RTN) in Aba Gerima watershed. There was lower RBY in forage grasses with Desmodium as compared to other fertilizer treatment groups.

Table 4.4 Effects of fertilizer treatments on root characteristics at the Aba Gerima watershed

Variables	RL (cm)	NRPP (No.)	S: R	RBY (t ha ⁻¹)	RSOC %	RTN
<i>Forage grasses</i>						
Napier grass	37.6 ^a	208.8 ^b	1.6	4.9 ^a	36.3 ^b	0.57 ^b
Desho grass	29.9 ^b	327.2 ^a	1.6	3.3 ^b	39.2 ^a	0.64 ^a
SL	**	***	ns	***	**	*
SEM	1.31	12.67	0.08	0.15	0.69	0.02
<i>Fertilizer treatments</i>						
Control	37.7	279.7 ^{ab}	1.6	3.8 ^{ab}	38.8	0.61
Desmodium	31.7	248.0 ^{ab}	1.8	3.6 ^b	38.0	0.59
FYM	33.5	311.3 ^a	1.5	4.4 ^{ab}	38.4	0.60
Desmodium& FYM	32.2	232.8 ^b	1.6	4.6 ^a	35.8	0.62
SL	ns	*	ns	*	ns	ns
SEM	1.85	17.92	0.11	0.21	0.97	0.02
Overall mean	33.8	268.0	1.6	4.1	37.8	0.60
CV (%)	13.4	16.4	16.9	12.4	6.3	9.9

Table 4.5 Effects of fertilizer treatments on root characteristics at Guder watershed

Variables	RL (cm)	NRPP (No.)	S: R	RBY (t ha ⁻¹)	RSOC %	RTN
<i>Forage grasses</i>						
Napier grass	29.0	396.3	4.4	1.4	33.6	0.95 ^a
Desho grass	26.5	485.5	4.6	1.3	32.5	0.70 ^b
SL	ns	ns	ns	ns	ns	*
SEM	1.07	45.36	0.45	0.12	0.92	0.06
<i>Fertilizer treatments</i>						
Control	27.5	523.7	4.9	1.3	35.9	0.90
Desmodium	26.6	358.2	4.2	1.2	33.8	0.83
FYM	28.6	431.5	4.0	1.5	31.3	0.69
Desmodium& FYM	28.2	450.3	4.9	1.5	31.1	0.89
SL	ns	ns	ns	ns	ns	ns
SEM	1.52	64.14	0.64	0.17	1.31	0.08
Overall mean	27.7	440.9	4.5	1.4	33.0	0.82
CV (%)	13.4	25.6	24.7	21.2	9.7	24.0

Values within a column that bear the same letter are not statistically different ($p < 0.05$); RL: root length; NRPP: number of roots per plant count; RBY: root yield; RSOC: root soil organic carbon; RTN: root total nitrogen

In addition, RL and RBY of Napier grass were higher than that of desho grass, while NRPP, RSOC, and RTN showed lower values for Napier grass in the same watershed. On the other hand, fertilizer treatments showed no variation in all root characteristics and root chemical properties at the Guder watershed. Moreover, in the same watershed except for RTN, the other root characteristics did not show significant ($p > 0.05$) variation between Napier and desho grass.

4.4. Discussion

4.4.1 Physicochemical properties of soil

Planting forage grasses with different fertilizer treatments had no effect on BD in our study. The lack of change in BD observed by us differed from that reported by Shirani *et al.* (2002), who found a significant decrease in soil BD immediately after harvesting a maize field treated with FYM. In a two-year field experiment in Iran, the same author discovered that root activity can increase soil porosity and decrease BD. However, the improvement in BD of soil planted with desho grass compared to Napier grass may be due to differences in growth habit and root biomass; desho grass has more tillers with many fibrous roots (Table 4.4 and 4.5), which may decrease soil erosion by increasing BD (Welle *et al.*, 2006), whereas Napier grass has fewer tillers with an erect growth habit and less fibrous roots.

Soil pH rises in both watersheds as a result of forage grass planting, though at Guder it rises significantly more. This could be related to the ground cover provided by forage grasses reduces runoff, soil erosion and associated basic cations which resulted improved soil organic matter and soil pH (Kumar *et al.*, 2019). Among the forage grasses tested in our study, desho grass improved pH the most; this may be due to its greater tillering capacity, which covers a wider area, implying that it has the potential to reduce runoff and soil loss (Welle *et al.*, 2006). According to Sarwar *et al.* (2010), compost releases alkaline substances and cations such as Ca^{2+} , Mg^{2+} , and K^{+} , which increase CEC and pH and counteract soil acidification.

We observed variations in some soil chemical properties at Aba Gerima after planting forage grasses with various fertilizer treatments. These variations could be attributed to variations in rainfall, temperature, and soil properties. Alternatively, according to different authors (Shirani

et al., 2002; Sharpley *et al.*, 2004; Abusuwar, 2019), manure application in both watersheds not only provides vital nutrients but also improves the chemical properties of the soil for subsequent forage production. Furthermore, manure application improved SOC and TN content significantly (Ma *et al.*, 2020). Besides, FYM increases soil macro elements such as NPK Eghball *et al.* (2004), resulting in maximum NPK uptake by the crop as well as improved SOC and available N, P, and K. (Srivastava *et al.*, 2014). Similar to our findings at Aba Gerima, increased N and C availability in the soil following manure application provides better nutrients for subsequent production and can be considered a substitute for chemical fertilizer (Utamy *etal.*, 2018).

4.4.2 Forage grass morphological characteristics

The forage grasses were relatively larger at middle elevations, which is similar to the findings of Bimrew Asmare *et al.* (2017) for desho grass. Environmental conditions such as rainfall, temperature, and soil properties conducive to plant growth may be factors contributing to morphological variations in forage grasses. Plant growth and yield are influenced by the amount and distribution of precipitation, the amount of sunlight, and soil nutrient content (Snyman, 2002). The temperature and moisture near the soil surface affect the germination and establishment of pastures (Altin *et al.*, 2011). Most morphological differences between the presence and/or absence of FYM could be attributed to the availability of essential nutrients provided by FYM for growth and production (Abusuwar, 2019) and greater soil moisture level under FYM as well as combined use of FYM and Desmodium in both watersheds (Appendix Fig. 4.4). Furthermore, FYM increases soil macro elements, such as nitrogen (N), phosphorous (P), and potassium (K) (Eghball *et al.*, 2004) which results increased growth of forage grasses.

Our results are consistent with those of (Bizelew Gelayenew *et al.*, 2020) who report that more tillers per plant contribute to higher DMY in Napier intercropped with vetch. In agreement with our study, Laidlaw (2005) reported that tiller mass is an important characteristic of grasses as it increases the chances of survival and quantity of available forage. The same author reported that greater numbers of tillers formed by some grass species allow them to achieve maximum development at an earlier age and recover faster after defoliation. The present study is consistent with those of (Taye Bayble *et al.*, 2007; Bimrew Asmare *et al.*, 2017), who found similar growth

characteristics for Napier grass and desho grass, respectively. Konlan *et al.* (2021) reported a difference in the number of tillers between *Brachiaria ruziziensis* and *Sorghum almum* in Ghana, which agrees with our finding that in the same agro-ecology, desho grass produces more tillers per plant than Napier grass. The increase in NTPP with FYM as well as the combined use of FYM and Desmodium that we observed is consistent with reports for other grasses (Taye Bayble *et al.*, 2007; Bimrew Asmare *et al.*, 2017).

The value for NTPP differs from the report of Rahetlah *et al.* (2014) in which NTPP at the first harvest did not differ between treatments and watersheds in our study. The differences might be related to differences among forage species used, climate, and soil properties. However, the height of Mott grass increased at all growth stages (109.7 - 116.6 cm) with the application of N/FYM (Bilal *et al.*, 2000), which is similar to the current study. In addition, the NTPP in the present study was relatively low as compared to Bilal *et al.* (2000) N/FYM treatment group (47.3 - 71.6/plant) in Napier grass. In plant growth, nitrogen is the most limiting nutrient in Ethiopian soil (Yihenew G/Selassie, 2015). The same author added it is found in chlorophyll, plant proteins, and nucleic acids, and it aids in vegetative development. The differences in N content between our results and those of previous studies might be associated with the addition of N fertilizer in those studies and differences in the rate of FYM application.

4.4.3 Dry matter and crude protein yield of forage grasses

The substantial increase in DMY and CPY of Napier grass treated with FYM as well as combined use of FYM and Desmodium might be associated with improvement of soil chemical properties, higher yield per frequency of harvest (Appendix Table 4.2 and 4.3), and increased soil moisture level (Appendix Fig. 4.4) in both watersheds. Furthermore, FYM increases soil macro elements, such as NPK (Eghball *et al.*, 2004), thereby resulting in maximum NPK uptake by the crop and improved SOC as well as available N, P, and K (Srivastava *et al.*, 2014) for increased DMY and CPY of forage grasses. Moreover, due to combined poultry and cow manure application, DMY increments ranged from 53.7 to 118% in the first season and from 146 to 514% in the second year (Abusuwar, 2019), which agrees with our findings. According to the report of Utamy *et al.* (2018), the availability of N and C in the soil after manure application might be considered adequate for subsequent cultivation of forage grasses. The

positive and significant correlation between DMY and CPY with PH and NTPP indicated higher yield in our study (Appendix Table 4.1). The DMY of forage grasses with FYM application in our study is consistent with the value reported by Tessema Zewdu *et al.* (2002) for application of manure on Napier grass. The negative association between LSR with DMY in our study (Appendix Table 4.1) agrees with the reports of different authors (Tessema Zewdu *et al.*, 2002; Bimrew Asmare *et al.*, 2017), which is an important factor associated with digestibility (Yasin *et al.*, 2003) and considerably affects the nutritive value of grass, as leaves contain higher levels of nutrients and lower fiber than stems (Tessema Zewdu, 2005).

On the other hand, there was an increment in most yield characteristics in 2019 as compared to 2018, notably DMY and CPY. This might be associated with a slight increase in both temperature and rainfall for both watersheds (Fig. 3.2 and 3.3) and the additive effect of FYM and Desmodium in increasing uptake and availability of essential soil nutrients (NPK) for improved yield and the perennial nature of forage grasses as they become established (Tessema Zewdu, 2005). Moreover, the same author reported that full growth of roots, stems, and leaves in plant developmental stages may contribute to variation in growth and yield of forage grasses.

There was lower DMY in either Napier or desho grass associated with Desmodium, which is contrary to the report of Gierus *et al.* (2012) in that companion grass growth was facilitated by the N transferred from forage legumes. The same author reported better grass DMY and, accordingly, higher mixed DMY in a legume–perennial ryegrass mixture. However, Maina *et al.* (2006) reported that *Desmodium intortum* has the potential to fix more N₂ but transfers only 5% of it to its companion grasses. Furthermore, Sant’Anna *et al.* (2018) stated that the contributions of legumes like Desmodium to N₂ fixation are relatively low in the first year but significantly improve in subsequent years. According to the same author, nitrogen in legumes derived from biological nitrogen fixation has a significant environmental advantage over synthetic nitrogen fertilizers. Our findings indicate that when integrating legumes like Desmodium with forage grasses, inorganic fertilization (urea) is required in the first year of planting for better forage grass establishment and DMY. According to our findings, organic fertilizers such as manure had no effect on the CP content of forage grasses, which agree with the report of Negasu Yiberkew *et al.* (2020) for *Brachiaria* hybrid Mulato II grass in Ethiopia.

In contrast to the current study, Taye Bayble *et al.* (2007) reported that combining Napier grass with *Desmodium* and *Lablab purpureus* improved forage grass CP content. In the current experiment, the mean CP content of desho grass and Napier grass was within the range reported for *Pennisetum* species by Kahindi *et al.* (2007).

4.4.4 Belowground root characteristics

The majority of below ground root characteristics of Napier and desho grasses differed from those observed by Negasu Yiberkew *et al.* (2020), who reported higher RL and NRPP in chemical fertilizer and manure treatments. The difference could be due to differences in forage species used, soil conditions, or climatic conditions in the experimental areas. The increase in RL for Napier grass compared to desho grass could be due to differences in plant spacing; plants with wider spacing produce the longest RL at low plant areal densities (Moniruzzaman, 2011). Furthermore, the higher RL and RBY for Napier grass compared to desho grass in our experiments may be related to plants with longer root structures; this leads to increased root biomass and thicker roots in the upper soil profile than in plants with small root systems (Figueroa-Bustos *et al.*, 2018). The higher RBY in Napier grass than in desho grass that we observed is consistent with the findings of Bolinder *et al.* (2002) for various forage grasses. The higher RBY at Aba Gerima could be attributed to differences in climate and soil properties, as reported by Bolinder *et al.* (2002) for various forage species. Furthermore, the variations in S: R ratio observed among Guder and Aba Gerima are consistent with the findings of Bolinder *et al.* (2002), who found that S: R varies with location and climate.

4.5. Conclusions

Our findings show that applying farmyard manure or in combination with *Desmodium intortum* significantly improved the growth characteristics, dry matter yield, and crude protein yield of Napier and desho grasses. Furthermore, it improved soil chemical properties at midland and moisture levels in both agro-ecologies. This research will help to ensure long-term feed availability in terms of quality and quantity for improved animal production by conserving soil health in environmentally friendly production systems. Thus, additional research on Napier grass and desho grass with integrated application of organic and inorganic fertilizer types for higher yields over longer periods of time would be beneficial in the future.

CHAPTER 5. NUTRITIONAL VALUE AND IN VITRO VOLATILE FATTY ACID PRODUCTION OF FORAGE GRASSES CULTIVATED USING FARMYARD MANURE AND *Desmodium intortum* INTERCROPPING IN THE UPPER BLUE NILE BASIN, ETHIOPIA

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Abstract

Integrating farmyard manure (FYM) and legume intercropping improves soil chemical and microbial properties, thereby increasing forage productivity and nutritional value. The purpose of this study was to evaluate how fertilizer treatments affected the chemical composition, in vitro gas production and organic matter digestibility (IVOMD), and volatile fatty acid production (VFA) of Napier and desho grasses in the upper Blue Nile basin of Ethiopia. Apart from ether extract content, the chemical composition of the fertilizer treatments in the Aba Gerima watershed did not differ significantly, whereas significant differences were observed in acid detergent fiber and crude protein contents at Guder. In both watersheds, Napier grass had significantly higher crude protein levels than desho grass. In Aba Gerima, ash content was significantly higher in 2018 than in 2019, but not in Guder. For Napier grass and desho grass, there were increased in IVOMD (6.7 vs 4.7%), metabolizable energy (5.5 vs 4.5%), and VFA production (23.1 vs 3.0%) in the *Desmodium intortum* plus FYM treatment than in the control

in Aba Gerima. In Guder, however, IVOMD (13.7 vs 4.6%), metabolizable energy (13.3 vs 3.3%), and VFA production (11.2 vs 5.6%) were higher in the same treatment for Napier grass and desho grass than in the control. This study suggests that *Desmodium intortum* plus FYM improves the nutritional value, IVOMD, and VFA production of Napier and desho grasses in midland and highland agro-ecologies of the Upper Blue Nile basin, facilitating their growth as alternative livestock feed for better production in these areas.

Key words: Dryland; Desho grass; Farmyard manure; in vitro digestibility; Volatile fatty acid

5.1 Introduction

The Ethiopian livestock sub-sector contributes significantly to both household and national economies (Behnke and Metaferia, 2013), despite the fact that animal productivity remains among the lowest in Africa. In most farming systems in Ethiopia, feed scarcity in both qualitative and quantitative dimensions is a major impediment to livestock production (FAO, 2010). Thus, increased livestock production can only be realized through the cultivation of high-yielding quality forages in a variety of agro-ecological settings (Tessema Zewdu *et al.*, 2002).

Grazing and crop residue provide more than 69.5% of the feed resources for ruminant animals in Ethiopia's highlands (CSA, 2019). The nutritional value of such feed resources, on the other hand, is characterized by a high cell wall content and a low protein, energy, and mineral content (Solomon Melaku, 2004). Improved forages, on the other hand, provide a reasonable source of nutrients for animal production while conserving soil fertility, water resources, and air quality (Chaudhry, 2008). The most common forage grasses used by livestock producers in northwestern Ethiopia are Napier grass (*Pennisetum purpureum*) and desho grass (*Pennisetum pedicellatum*) (Tessema Zewdu *et al.*, 2002; Bimrew Asmare *et al.*, 2017). At the height of one meter harvest, Napier grass has 65.5% in vitro organic matter digestibility (IVOMD) and 9.0 MJ kg⁻¹ metabolizable energy (ME), according to (Tessema Zewdu *et al.*, 2002). Desho grass, on the other hand, has a mean IVOMD and ME value of 43.9% and 6.2 MJ kg⁻¹, respectively (Bimrew Asmare *et al.*, 2017).

Forage grass chemical composition varies with soil type, landscape, management practice, and other environmental factors that influence forage yield and quality (Gemiyo *et al.*, 2013). Manure improves the physical, chemical, and microbial properties of soil, increasing productivity and nutritional value while remaining environmentally sustainable (Abusuwar, 2019). Farmyard manure (FYM) has a high organic matter content and serves as a source of plant nutrients through decomposition and nutrient release. Intercropping compatible forage grasses with legumes like *Desmodium intortum* (Desmodium) improves and maintains soil fertility via nitrogen fixation, increasing productivity and profitability (Yildirim and Guvenc, 2005). Thus, for improved ruminant livestock production, the effects of integrated FYM and Desmodium intercropping on the nutritional value and volatile fatty acid (VFA) production of forage grasses need further investigation.

Chemical composition, IVOMD, and VFA production are useful feed evaluation indicators for ruminant livestock production ration balancing. More degradable by-products have higher IVOMD values and a wider range of ruminal fermentability (García-Rodríguez *et al.*, 2019) for improved animal production. In this case, using in vitro gas production to evaluate forage digestibility is a quick and low-cost method of determining ruminant feed nutritive value (Fievez *et al.*, 2005). It is easy to use, fast, and can handle a large number of samples at once. In tropical forage grasses, Melkamu Bezabih *et al.* (2014) discovered a link between forage chemical composition and in vitro fermentation parameters. In contrast, nitrogen (N) fertilization improved biomass yield, crude protein, cellulose, and lignin content by decreasing the energy content available for metabolism and slowing the fermentation rate, as well as decreasing in vitro dry matter disappearance and cumulative gas production (Cui *et al.*, 2016).

Previous research has found that applying FYM improves forage grass growth and biomass yield (Utamy *et al.*, 2018; García-Rodríguez *et al.*, 2019). However, there is little scientific evidence on the effects of integrated FYM and Desmodium intercropping as fertilizer treatments and season of production on forage grass nutritional value, IVOMD, VFA, and methane production. Thus, the objective of this study was to assess the effects of FYM and *Desmodium intortum* on the chemical composition, IVOMD, VFA, and methane production of

Napier and desho grasses in midland and highland agro-ecologies in dryland areas of Ethiopia's upper Blue Nile basin.

5.2 Materials and Methods

5.2.1 Study areas

The research was undertaken in two watersheds, Aba Gerima and Guder, of the upper Blue Nile basin, Amhara region, Ethiopia (Fig. 3.1); these watersheds represent midland and highland agro-ecologies, respectively. The Aba Gerima watershed lies in the Bahir Dar Zuria district within the region 37° 29' 24" E to 37° 32' 24" E longitude and 11° 38' 24" N to 11° 40' 12" N latitude at 1970 m above sea level. The mean annual rainfall is 1558 mm, with most rain occurring from June to September. In the two study years, the mean minimum and mean maximum annual temperature varied from 13.3 to 27.6 °C. The main means of livelihood for farmers in the watershed are mixed crop cultivation and livestock rearing. The main livestock species are cattle, sheep, goat, and donkey (Kindye Ebabu *et al.*, 2019). The Guder watershed is located in the Fagta Lekoma district 10°59'34"N to 11°01'01"N latitude and 36°54'09"E to 36°55'55"E longitude at 2577 m above sea level. It has higher annual rainfall (mean, 2370 mm) and lower mean annual temperatures than the Aba Gerima watershed: the data from a nearby meteorological station showed that the mean minimum and mean maximum annual temperature in the Guder watershed varied from 10.6 to 25.2 °C. The main livestock species reared in the Guder watershed are cattle, sheep, and horse (Kindye Ebabu *et al.*, 2019).

5.2.2 Experimental design and treatments

A randomized complete block design with a 2×4×2 factorial arrangement was used for the experiment for two consecutive years (2018 and 2019). The factors were the type of forage grass (two levels: Napier and desho grass), the fertilizer treatments (four levels: no fertilizer [control], Desmodium, FYM, and a combination of Desmodium and FYM [hereafter, "Desmodium plus FYM"]), and the year (two levels: 2018 and 2019) with three replications. The experiment was carried out in both watersheds under rain-fed conditions. The FYM (cattle manure) used in the experiment was collected from the Bahir Dar University dairy farm, Zenzelma campus, Ethiopia, and consisted of cattle manure with a small amount of roughage feed residues and urine. One month before planting forage grasses, FYM was applied at a rate

of 12 t ha⁻¹ (Tessema Zewudu *et al.*, 2002; Desalegn Ayichew, 2017). The FYM was 17.5% organic carbon, 1.5% total nitrogen, 11.7:1 carbon to nitrogen ratio, 32.8 mg kg⁻¹ available phosphorous, and a pH of 7.4. Both forage grasses were planted in 2018 with healthy root splits obtained from a nearby research facility, and data was collected over the course of two years. Napier grass was planted with a 1-m inter-row spacing and a 50 cm intra-row spacing, whereas desho grass was planted with a 50 cm inter- and intra-row spacing. *Desmodium intortum* was sown between two rows of forage grass one month after the grass was planted for intercropping. For better forage grass establishment and production, each plot was kept weed-free manually throughout the experiment.

5.2.3 Sample collection and preparation

Healthy root splits were used to plant the forage grasses; Desho grass was planted 50 cm between inter and intra rows. Napier grass, on the other hand, was planted at 1 m inter-row spacing and 50 cm intra-row spacing. For better biomass yield and nutritional value, Napier grass was clipped at a height of 1 m (Tessema Zewdu *et al.*, 2003a), while 50–60 cm was used for desho for each year (Bereket Dindamo *et al.*, 2016). Harvested fresh samples were immediately chopped manually into small pieces with a sickle, placed inside a plastic bag, and weighed. The samples were then transported from the field to the College of Agriculture and Environmental Sciences at Bahir Dar University. All harvested samples from each plot were thoroughly mixed, and a representative whole forage sample was taken for each watershed in each year. The samples were oven-dried at 60 °C for 72 h to a constant weight. The dried samples were then ground to pass through a 1-mm sieve and placed in air-tight plastic bags to determine chemical composition, gas production, IVOMD, and VFA production.

5.2.4 Chemical analysis

The determination of dry matter (DM), total ash, and crude protein (CP) followed the procedures of the Association of Official Analytical Chemists (AOAC, 1990), while ether extract (EE) was analyzed with ethyl ether using gravimetric methods in the same procedure. Van Soest *et al.* (1991) was used to determine the contents of the fiber fractions neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL). Total ash content was determined by combusting the samples in a muffle furnace at 550 °C for 3 h (AOAC,

1990). The samples were ignited and nitrogen content was determined with a carbon nitrogen elemental analyzer (JM1000CN; J-Science Lab Co., Ltd., Kyoto, Japan) (Appendix Fig. 5.1). The CP content was calculated by multiplying the nitrogen content by a factor of 6.25.

5.2.5 In vitro gas production, organic matter digestibility and production of VFAs

The syringe method was used for in vitro fermentation to determine IVOMD of the forage grasses by (Menke and Steingass, 1988). Two Japanese Corriedale sheep were rumen-cannulated to collect rumen fluid for in vitro fermentation. The sheep were fed fresh forage dominated by Timothy grass and were given free access to water and mineral licks. Samples of rumen fluid were obtained from both sheep at 3 h after the morning feed. The samples were flushed with CO₂ and strained through two layers of cheesecloth into a prewarmed, insulated thermos flask. The filtered rumen fluid was combined in a 1:2 ratio with a culture medium containing macro minerals, microminerals, and bicarbonate buffer reducing solution, and kept at 39 °C with a constant flow of CO₂ to maintain anaerobic conditions (Appendix Figure 4.3). Then, as Menke and Steingass (1988) described, 0.2 g of DM forage samples were accurately weighed and inserted into 100-ml glass syringes; two syringes without substrate were incubated as controls, and 30 mL of rumen fluid + medium was added under a stream of CO₂, closed with rubber stoppers and crimp seal to prevent the accumulation of fermentation gases. The syringes were placed in a rotor inside an incubator set to 39 °C and rotated once every minute (Appendix Figure 5.3). At Shimane University in Japan, cumulative gas volume measurements of samples were taken before incubation (0 h) and then after 3, 6, 12, 24, 48, 72, and 96 h of incubation.

IVOMD was estimated on the basis of 24 h gas production (GP24; ml 0.2 g⁻¹ DM) and CP content (g kg⁻¹ DM) by using Equation 1, while metabolizable energy (ME) content (MJ kg⁻¹ DM) was estimated using GP24, CP content, and EE content (g kg⁻¹ DM) using equation 2 as described by (Menke and Steingass, 1988).

$$\text{IVOMD (\%)} = 18.53 + 0.9239 \times \text{GP24} + 0.0540 \times \text{CP} \text{ ----- (1)}$$

$$\text{ME (MJ kg}^{-1}\text{ DM)} = 2.43 + 0.1206 \times \text{GP24} + 0.0069 \times \text{CP} + 0.0187 \times \text{EE} \text{ ----- (2)}$$

The gross energy of the forage grasses was determined using a bomb calorimeter (Shimadzu, Japan) (Appendix Figure 5.2).

In the analysis of VFA production, 5 ml was collected at the end of in vitro gas production and centrifuged for 15 minutes at 4 °C (Appendix Figure 5.4). Then the supernatant was transferred to a micro-centrifuge tube and stored at -20 °C until further analysis. The frozen samples were defrosted and filtered through gauze to remove foreign materials before being centrifuged at 10,000 RPM for 30 minutes at 4 °C. Half milliliter of supernatant was used to determine VFA concentrations of acetic, propionic, n-butyric, isobutyric acids by using a gas chromatography machine (Shimadizu Corp., Kyoto, Japan). For the gas chromatography, we used the standard solution, which included 10 mmol L⁻¹ of each of the four acids and 10 mmol L⁻¹ of crotonic acid as the internal standard. The samples were therefore mixed with the internal standard for analysis. By using the determined VFA concentrations, the methane (CH₄) emissions were calculated by using Equation 3, which was developed by (Moss *et al.*, 2000).

$$\text{CH}_4 (\text{mmol L}^{-1}) = 0.45 \times \text{acetate} - 0.275 \times \text{propionate} + 0.40 \times \text{butyrate} \text{ ----- (3)}$$

where acetate, propionate, and butyrate are the concentrations in mmol L⁻¹.

5.2.6 Statistical analysis

Data on chemical composition, in-vitro gas production, IVOMD, and concentrations of VFA produced through in-vitro gas production of forage grasses were analyzed using the general linear model procedure of Statistical Analysis Software SAS JMP13 (SAS, 2016) for each watershed separately. Tukey's honestly significant difference test was used to determine whether there were significant differences between treatment means.

5.3. Results

5.3.1 Forage grass chemical composition under various fertilizer treatments

The effects of fertilizer treatments on the chemical composition of the forage grasses are presented in Table 5.1 (Aba Gerima) and Table 5.2 (Guder) watershed. Fertilizer treatments had no effect on the chemical composition of the forage grasses in the Aba Gerima watershed, with the exception of EE ($P < 0.001$); EE values ranged from 2.1% in forage grasses cultivated with Desmodium to 2.6% in those cultivated with Desmodium plus FYM. At the Aba Gerima watershed, the EE content of the FYM and Desmodium + FYM fertilizer treatments in Napier grass was 14.4–17.9% higher than the control, whereas desho grass did not show an increase in the same fertilizer treatments.

The CP and NDF contents of Napier grass were significantly higher than those of desho grass, while the ADF and ADL contents of the two forage grasses at the Aba Gerima watershed were comparable. In our study, the concentrations of NDF ranged from 69.9% in desho grass to 72.5% in Napier grass at Aba Gerima, while 68.1% to 69.7% for desho and Napier grass, respectively at Guder watershed. Fertilizer treatments had no effect on the CP content of Napier or desho grass in Aba Gerima, but variation was observed in the Guder watershed. In the same watershed, the NDF content of FYM and Desmodium plus FYM fertilizer treatments was 6.5% higher in Napier grass, while desho grass decreased by 6.0% and 3.9%, respectively.

Furthermore, the EE and GE contents of desho grass were significantly higher ($P < 0.001$) than those of Napier grass. In 2019, the NDF and EE contents were significantly higher ($P < 0.001$) than in 2018, while the ash content was lower. The other chemical composition variables were not significantly different between the two years. The GE content in Napier grass was 3.7% higher in the FYM fertilizer treatment than the control at the Aba Gerima watersheds, while it was 4.6% lower in the desho grass in the same fertilizer treatment (Appendix Table 5.3).

In the Guder watershed, fertilizer treatment had a significant ($P < 0.05$) effect on ADF, EE, and CP contents, but variation in ash, NDF, ADL, and GE was not observed in similar treatments. The fiber fraction values tended to be higher in the control treatment than in the other fertilizer treatments, but this difference was only significant for ADF (control versus FYM; control versus Desmodium plus FYM). The fiber fraction values of the two forage grasses did not differ significantly. Napier grass contained significantly more ADL, EE, and CP than desho grass, while the latter contained more ash and GE.

Table 5.1 Effects of fertilizer treatments and year on the chemical composition of forage grasses at the Aba Gerima watershed

Variables	Ash	NDF	ADF	ADL	EE	CP	GE
	% Of DM				g kg ⁻¹ DM		
<i>Fertilizer treatment (F)</i>							
Control	6.1	70.9	39.1	11.1	2.4 ^b	85.0	12.8
Desm	6.3	70.6	38.6	10.2	2.1 ^c	78.6	13.0
FYM	6.0	71.3	42.0	11.3	2.4 ^b	78.3	12.7
Desm& FYM	6.1	72.0	42.6	11.7	2.6 ^a	80.8	12.8
± SEM	0.08	0.86	1.44	0.55	0.03	3.07	0.10
<i>Forage grass (FS)</i>							
Desho grass	6.3 ^a	69.9 ^b	39.5	11.2	3.0 ^a	70.0 ^b	13.0 ^a
Napier grass	6.0 ^b	72.5 ^a	41.7	10.9	1.8 ^b	91.3 ^a	12.7 ^b
± SEM	0.06	0.61	1.01	0.39	0.02	2.17	0.07
<i>Year (Y)</i>							
2018	6.3 ^a	69.2 ^b	41.2	12.1 ^a	2.3 ^b	81.7	12.8
2019	5.9 ^b	73.2 ^a	40.0	10.0 ^b	2.5 ^a	79.6	12.9
± SEM	0.06	0.61	1.01	0.39	0.02	2.17	0.07
Overall mean	6.1	71.2	40.6	11.1	2.4	80.6	12.8
<i>P-values</i>							
F	0.2753	0.7236	0.1340	0.2925	< 0.0001	0.3991	0.1994
FS	0.0003	0.0043	0.1347	0.4873	< 0.0001	< 0.0001	0.0109
Y	< 0.0001	< 0.0001	0.3738	0.0008	< 0.0001	0.4844	0.5318
F*FS	0.6920	0.0045	0.8172	0.8329	<.0001	0.4012	0.0013
F*Y	0.3584	0.1512	0.2891	0.3197	0.9542	0.5698	1.0000
FS*Y	0.0881	0.1138	0.1506	0.0122	0.0810	0.4672	0.9947

Means with different superscripts in a column are significantly different ($P < 0.05$, Tukey's test); Control, no fertilizer treatment.

In comparison to the control, fertilizer treatments FYM and Desmodium plus FYM (2.6 and 1.4%) increased the CP content of Napier grass, while desho grass increased by 4.9–5.2% in the same fertilizer treatments. Under FYM and Desmodium plus FYM fertilizer treatments, the NDF content was 0.01–7.4% lower in Napier grass and 5.6–2.2% lower in desho grass than in control (Appendix Table 5.4). However, in Aba Gelima, NDF and EE were higher in 2018; whereas in Guder, NDF and EE were higher in 2019. In addition, in the Aba Gerima watershed, the ADL content was significantly higher in 2018 than in 2019.

Table 5.2 Chemical composition of forage grasses cultivated using various fertilizer treatments at the Guder watershed

Variables	Ash	NDF	ADF	ADL	EE	CP	GE
	% Of DM				g kg ⁻¹ DM		
<i>Fertilizer treatment (F)</i>							
Control	6.2	70.5	42.2 ^a	12.0	2.2 ^b	114.6 ^b	12.7
Desm	6.3	69.1	38.4 ^b	11.6	2.2 ^b	107.8 ^c	12.5
FYM	6.2	68.9	39.3 ^{ab}	12.0	2.5 ^a	118.9 ^a	12.6
Desm& FYM	6.2	67.3	38.6 ^b	11.7	2.6 ^a	118.3 ^a	12.5
± SEM	0.10	0.80	0.85	0.52	0.03	2.90	0.14
<i>Forage grass (FS)</i>							
Desho grass	6.3 ^a	68.1	39.4	11.0 ^b	1.6 ^b	98.2 ^b	12.8 ^a
Napier grass	6.1 ^b	69.7	39.9	12.7 ^a	3.1 ^a	131.6 ^a	12.3 ^b
± SEM	0.07	0.57	0.60	0.37	0.02	2.05	0.10
<i>Year (Y)</i>							
2018	6.1	67.0 ^b	40.2	13.1 ^a	2.3 ^b	114.0	12.6
2019	6.3	70.8 ^a	39.1	10.5 ^b	2.5 ^a	115.8	12.6
± SEM	0.07	0.57	0.60	0.37	0.02	2.17	0.10
Overall mean	6.2	68.9	39.8	11.8	2.4	114.9	12.6
<i>P-values</i>							
F	0.8773	0.0608	0.0113	0.9128	< 0.0001	0.0412	0.5453
FS	0.0109	0.0676	0.5427	0.0031	< 0.0001	< 0.0001	0.0011
Y	0.0890	< 0.0001	0.1983	< 0.0001	< 0.0001	0.5497	0.6501
F*FS	0.3649	0.0208	0.3815	0.7172	0.0139	0.9550	0.3814
F*Y	0.5003	0.2143	0.2049	0.8463	0.7136	0.0045	1.0000
FS*Y	0.7808	0.2170	0.5806	0.0015	0.0973	< 0.0001	0.9929

Means with different superscripts in a column are significantly different ($P < 0.05$; Tukey's test); Control, no fertilizer treatment.

Abbreviations: ADF, acid detergent fiber; ADL, acid detergent lignin; CP, crude protein; Desm, *Desmodium intortum*; DM, dry matter; EE, ether extract; FYM, farmyard manure; GE, gross energy; NDF, neutral detergent fiber.

5.3.2 Effects of fertilizer treatment on GP, IVOMD, and VFAs

The effect of fertilizer treatment and year on GP24, IVOMD, and ME of forage grasses are shown in Table 5.3 (Aba Gerima) and Table 5.4 (Guder) while individual and total VFAs production presented in Appendix Table 5.1 (Aba Gerima) and Appendix Table 5.2 (Guder) watersheds. In both watersheds, the value for GP24 was significantly lower in the control and

Desmodium intortum treatments than in the FYM or Desmodium plus FYM treatments. Furthermore, in both watersheds, the IVOMD value increased in the order of control < Desmodium < FYM < Desmodium plus FYM (Table 5.3 and 5.4). When compared to the control, the GP content of Napier grass and desho grass increased by 3.5–12.4% and 2.9–8.6%, respectively, in the FYM and Desmodium plus FYM fertilizer treatments at the Aba Gerima watershed. Furthermore, the value for IVOMD increased in Napier grass by 1.2–6.7% and desho grass by 1.0–4.7% in the same fertilizer treatment than the control (Appendix Table 5.5). The IVOMD value in the same watershed ranged from 48.9% (2018) production year to 58.7% (2019) production year, with an overall mean of 53.8%; in Guder, it ranged from 52.9% (Napier grass) to 59.9% (desho grass), with an overall mean of 56.4%.

Desmodium plus FYM produced significantly higher IVOMD and ME values than all other treatments in both watersheds (Tables 5.3 and 5.4). Desho grass had significantly higher ($P < 0.001$) GP24, IVOMD, and ME than Napier grass in both watersheds: the mean GP24 values for desho grass and Napier grass at the Aba Gerima watershed were 38.7 and 28.2 ml 0.2 g⁻¹ DM, respectively; and 39.0 and 29.5 ml 0.2 g⁻¹ DM, respectively, at the Guder watershed (Appendix Table 5.4). In both watersheds, GP24, IVOMD, and ME were significantly higher ($P < 0.001$) in 2019 than in 2018.

There was a significant effect ($P < 0.001$) for the two-way interaction in forage grass × fertilizer treatment and forage grass × year in the case of GP24, IVOMD, and ME, as well as for the three-way interaction of forage grass × fertilizer treatment × year. In both years desho grass under FYM and Desmodium plus FYM decreased GP, IVOMD and ME concentration than the control and with Desmodium in Aba Gerima watershed but not in Guder. In addition, the three-way combination of forage grass (desho), fertilizer treatment (Desmodium plus FYM), and production year (2019) resulted in significantly higher ($P < 0.001$) GP24, IVOMD, and ME values than the other combinations of these three variables (Tables 5.3 and 5.4) in both watersheds.

Table 5.3 Results of Tukey's tests exploring the interaction effects of forage grasses, fertilizer treatments and year on GP24, IVOMD, and ME contents at Aba Gerima

Fertilizer sources	Factors		GP24	IVOMD	ME
	Forage grass	year	ml 0.2g ⁻¹ DM	%	MJ kg ⁻¹
Control	Desho	2019	45.0 ^{ab}	54.1 ^{ab}	9.2 ^a
Desm	Desho	2019	47.0 ^a	65.3 ^{ab}	9.0 ^{ab}
FYM	Desho	2019	44.0 ^b	62.6 ^b	8.9 ^{ab}
Desm& FYM	Desho	2019	47.3 ^a	66.0 ^a	8.7 ^b
Control	Desho	2018	30.1 ^d	50.3 ^{def}	7.2 ^{de}
Desm	Desho	2018	28.2 ^{de}	48.9 ^{efg}	6.8 ^{ef}
FYM	Desho	2018	33.3 ^c	53.1 ^{cd}	7.5 ^{cd}
Desm& FYM	Desho	2018	34.8 ^c	54.1 ^c	7.6 ^c
Control	Napier	2019	29.0 ^d	50.5 ^{de}	6.9 ^e
Desm	Napier	2019	34.0 ^c	54.7 ^c	6.4 ^g
FYM	Napier	2019	30.0 ^d	51.1 ^{de}	6.9 ^e
Desm& FYM	Napier	2019	34.0 ^c	55.0 ^c	7.4 ^{cd}
Control	Napier	2018	23.4 ^f	45.2 ^h	6.3 ^g
Desm	Napier	2018	25.1 ^f	46.3 ^{gh}	6.4 ^g
FYM	Napier	2018	24.3 ^f	45.4 ^h	6.3 ^g
Desm& FYM	Napier	2018	25.8 ^{ef}	47.5 ^{fgh}	6.5 ^{fg}
Overall mean			33.5	53.8	7.43
SEM			0.565	0.397	0.075
P-values			0.0015	0.0134	0.0196
CV (%)			2.9	1.8	1.7

Means with different superscript letters in a column are significantly different ($P < 0.05$).

Abbreviations: CV, coefficient of variation; Desm, *Desmodium intortum*; F, fertilizer treatments; FYM, farmyard manure; GP24, 24-h gas production; IVOMD, *in vitro* organic matter digestibility; ME, metabolizable energy; SEM, standard error of mean.

In both watersheds, the forage grass $\times$ fertilizer interaction significantly ($P < 0.001$) influenced the concentrations of acetate (A), propionate (Pr), total VFA (TVFA), and methane (CH₄), as well as the A:Pr ratio. The proportions of A (1.4–8.7%), Pr (10.0–15%), and TVFA (4.2–11.2%) were higher in the FYM and Desmodium plus FYM treatments than in the control at the Guder

watershed. In contrast, most VFA proportions for desho grass decreased under similar treatment conditions (Appendix Table 5.6). The A and Pr values in the control group were significantly lower than those in the other treatment groups in the same watershed, with the exception of A in the FYM group and Pr in the Desmodium group (Appendix Table 5.1 and 5.2).

In the Aba Gerima watershed, the concentrations of A and Pr were significantly higher ($P < 0.001$) after the application of FYM compared to other treatments, whereas they were significantly higher after the application of Desmodium plus FYM in the Guder watershed. The lowest concentrations of A and Pr were observed in Desmodium treatment groups in the Aba Gerima watershed (Appendix Table 5.1) and in the control treatment at Guder watershed; these results were statistically significant except for A in the control vs FYM group and Pr in the control vs Desmodium group in the Guder watershed (Appendix Table 5.2).

Farmyard manure and Desmodium plus FYM increased the concentrations of most VFAs, whereas the concentrations of B and V did not differ significantly among fertilizer treatments in the Guder watershed. In both watersheds, A:Pr ratio was significantly higher in Desmodium plus FYM than in the other treatment groups. Furthermore, methane production in FYM and Desmodium plus FYM was significantly higher ($P < 0.001$) than in other treatment groups in the Aba Gerima watershed, while it was significantly lower ($P < 0.001$) in the FYM treatment group than in others in the Guder watershed.

Acetate concentrations were significantly higher in Napier grass than in desho grass, and other VFA concentrations did not differ significantly by forage grass type. The A:Pr ratio for Napier grass was significantly higher in both watersheds than for desho grass. Acetate, TVFA, and methane production in both watersheds were significantly higher ($P < 0.001$) in 2019 than in 2018, whereas other VFAs did not differ significantly by production year. The A:Pr ratio at Aba Gerima was higher in 2019 than in 2018, but no variation was observed at the Guder watershed (Appendix Tables 5.1 and 5.2).

Table 5.4 Results of Tukey's tests exploring the interaction effects of forage grasses, fertilizer treatments, and year on GP24, IVOMD, and ME contents at Guder

Fertilizer sources	Factors Forage grass	year	GP ml 0.2g ⁻¹ DM	IVOMD %	ME MJ kg ⁻¹
Control	Desho	2019	44.6 ^b	63.5 ^b	8.6 ^a
Desm	Desho	2019	32.0 ^f	52.0 ^d	7.1 ^c
FYM	Desho	2019	44.0 ^b	64.7 ^{ab}	8.6 ^a
Desm& FYM	Desho	2019	47.0 ^a	67.1 ^a	8.9 ^a
Control	Desho	2018	34.4 ^{def}	56.5 ^c	7.7 ^b
Desm	Desho	2018	36.9 ^{de}	59.4 ^c	8.1 ^b
FYM	Desho	2018	36.5 ^{de}	57.3 ^c	7.7 ^b
Desm& FYM	Desho	2018	37.0 ^d	58.6 ^c	7.9 ^b
Control	Napier	2019	26.0 ^g	50.2 ^{de}	7.0 ^c
Desm	Napier	2019	28.0 ^g	51.5 ^{de}	7.2 ^c
FYM	Napier	2019	34.0 ^{ef}	58.0 ^c	8.0 ^b
Desm& FYM	Napier	2019	41.0 ^c	64.7 ^{ab}	8.9 ^a
Control	Napier	2018	25.4 ^g	48.6 ^e	6.9 ^c
Desm	Napier	2018	26.7 ^g	49.7 ^{de}	7.1 ^c
FYM	Napier	2018	27.9 ^g	50.8 ^{de}	7.1 ^c
Desm& FYM	Napier	2018	27.2 ^g	49.9 ^{de}	7.1 ^c
Overall mean			34.2	56.4	7.8
SEM			0.564	0.580	0.077
P-value			<.0001	<.0001	<.0001
CV (%)			2.9	1.8	1.7

Means with different superscript letters in a column are significantly different ($P < 0.05$).

5.3.3 Correlation between chemical composition, IVOMD, and VFA production

The associations between chemical composition, IVOMD, and VFA production of forage grasses under fertilizer treatments and production years are presented in Table 5.5. There were non-significant correlations between CP content and NDF, ADF, and ADL content. The content of CP was significantly inversely related to the content of GP24 ($r = -0.569$, $P < 0.01$), IVOMD ($r = -0.378$, $P < 0.001$), and methane production ($r = -0.505$, $P < 0.05$). IVOMD ($r = 0.947$, $P < 0.001$) and ME ($r = 0.973$, $P < 0.001$) were significantly and strongly positively correlated with

GP24, but not methane production ($r = 0.421$, $P > 0.05$). Furthermore, IVOMD demonstrated a significant and strong positive correlation with ME ($r = 0.999$, $P < 0.001$) as well as a significant and strong correlation with TVFA ($r = 0.741$, $P < 0.05$). ME and TVFA had a significant positive and strong positive correlation ($r = 0.741$; $P < 0.05$), but there was no significant correlation between ME and methane production. Finally, a strong and significant positive correlation ($r = 0.707$, $P < 0.05$) was discovered between TVFA and methane production.

Table 5.5 Correlation between chemical composition, in vitro organic matter digestibility, and VFA production of forage grasses

	CP	NDF	ADF	ADL	GP24	IVOMD	ME	TVFA	CH ₄
CP	1	0.215 ^{ns}	0.119 ^{ns}	0.536 ^{ns}	-0.569 ^{**}	-0.378 ^{**}	-0.369 ^{ns}	-0.507 ^{ns}	-0.505 [*]
NDF		1	0.677 ^{ns}	0.225 ^{ns}	-0.384 ^{ns}	-0.327 ^{ns}	-0.327 ^{ns}	0.251 ^{ns}	0.534 ^{ns}
ADF			1	0.323 ^{ns}	-0.140 ^{ns}	-0.099 ^{ns}	-0.104 ^{ns}	0.256 ^{ns}	0.309 ^{ns}
ADL				1	-0.630 ^{ns}	-0.599 ^{ns}	-0.593 ^{ns}	-0.348 [*]	-0.640 [*]
GP24					1	0.974 ^{***}	0.973 ^{***}	0.759 [*]	0.421 ^{ns}
IVOMD						1	0.999 ^{***}	0.741 [*]	0.397 ^{ns}
ME							1	0.741 [*]	0.390 ^{ns}
TVFA								1	0.707 [*]
CH ₄									1

Values shown are Pearson's correlation coefficients; * $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; ns, not significant.

Abbreviations: ADF, acid detergent fiber in %; ADL, acid detergent lignin in %; CH₄, methane in mmol L⁻¹; CP, crude protein; GP24: 24-h gas production in ml 0.2g⁻¹ DM; IVOMD, in vitro organic matter digestibility in %, ME, metabolizable energy; NDF, neutral detergent fiber in %; TVFA, total volatile fatty acids in mmol L⁻¹.

5.4. Discussion

5.4.1 Chemical composition of forage grasses

The present study at Aba Gerima watershed is contrary to the finding of Kering *et al.* (2011), who reported that N fertilization increased CP content and decreased NDF and ADF contents in Bermuda grass (*Cynodon dactylon* L.). The discrepancy might be related to variation in the fertilizer sources used, climatic conditions, and forage grasses used. Our results agree with the

findings of Meale *et al.* (2012) who reported that concentrations of NDF ranged from 67.1 to 71.3% in comparable forage grasses in Ghana. The NDF contents in our study were above the critical level (60.0%) that adversely affects voluntary dry matter intake and feed conversion efficiency in ruminant animals (Meissner *et al.*, 1991). This might be because both the forage grasses were tropical forages characterized by fibrous feed with high fiber content consisting of structural carbohydrates.

Conversely, the NDF values reported in our study were below the maximum cell wall concentration (70%–75%) that does not affect intake and animal performance in beef cattle (Buxton, 1996). However, the same author reported that high producing dairy cows need lower NDF content in feeds for adequate energy and fiber in the diets; for such animals, the forage grasses tested here would need additional supplemental quality feeds with lower fiber content for better feed intake and digestibility. The NDF values for Napier grass were higher than that in the previous report of Napier grass grown with Desmodium or the legume lablab (*Lablab purpureus*) in Northwestern Ethiopia (Taye Bayble *et al.*, 2007). Here, the lower fiber content in desho compared with Napier grass in both watersheds might be related to the larger leaf to stem proportion in desho grass.

Unlike in our study, where fertilizer type did not significantly affect total ash content of desho or Napier grass, a previous study also performed in northwestern Ethiopia found that total ash content was higher in manure-treated desho grass than that grown without fertilizer (Biniam Mihret *et al.*, 2018). Moreover, Ayub *et al.* (2002) reported that total ash content of sorghum grass was significantly affected by the level of nitrogen fertilization in Pakistan. On the other hand, Tessema Zewdu *et al.* (2002) reported lower ash content in Napier grass planted with inorganic fertilizer (15.1-15.7%) but higher ash content in Napier grass without fertilizer and with manure at relatively higher level (17.1%), which is different from our fertilizer treatments in our study. In agreement with our study, Heseen *et al.* (2017) reported that application of organic and inorganic fertilizers did not affect total ash content of sorghum cultivars at a site in Egypt.

In our study, the variation in CP content of forage grasses under various fertilizer treatments was not consistent across the two agro-ecologies. Similar to our results for the forage grasses at the Aba Gerima watershed, Negasu Yiberkew *et al.* (2020) reported that the use of organic fertilizer, like manure, did not influence the CP content of *Brachiaria* Hybrid Mulato II grass, when grown in the lowlands of northwestern Ethiopia. In contrast, Taye Bayble *et al.* (2007) found that integrating Napier grass with *Desmodium* and lablab improved the grass's CP content. The difference between our results and those in the previous reports might relate to differences in the soil types and climatic conditions in the various regions in northwestern Ethiopia and/or the types of forage grasses used. Our results from the Guder watershed are in line with the findings of various studies in which CP content of forage grasses improved noticeably with application of fertilizer (Ahmad *et al.*, 2013; Kamal *et al.*, 2017; McRoberts *et al.*, 2018; Jimoh *et al.*, 2019).

The relatively high CP content achieved in the highlands of the Guder watershed than the midlands of the Aba Gerima watershed might be associated with the Guder watershed's having relatively lower temperatures, higher rainfall, lower radiation, and different soil properties. In addition, Rochana *et al.* (2016) reported that the crude protein is directly related with the available nitrogen content in the leaves and stem. The same author added it is assumed that under lower temperature environment the inorganic nitrogen in the form of nitrate was more, which might be due to slow process of nitrogen assimilation. The result is in agreement with that of Rochana *et al.* (2016), who found that forages in highland regions tend to have a better CP yield than those in midland regions, but conflicts with the reports of Bimrew Asmare *et al.* (2017) who found higher CP content in midland than highland agro-ecologies. Crude protein levels above 70 g kg⁻¹ DM, such as those observed in our study, increase microbial multiplication, thus improving fermentation in the rumen (Njidda *et al.*, 2010).

Our finding that the EE content of the forage grasses was higher with *Desmodium* plus FYM treatment than in the control in both watersheds suggests that such integrated treatment could provide ruminants with more energy content. Consistent with our results at the Guder watershed, but not at Aba Gerima watershed, Jimoh *et al.* (2019) reported a significant difference in EE content between fertilized (manure) and unfertilized treatments. The same authors reported that

EE content of forage grasses differs with the animal origin of the manure: a higher value was reported for grasses grown using cattle and swine manure than poultry manure or no fertilizer. Ayub *et al.* (2002) reported the EE content increased as the level of nitrogen fertilizer increased; the minimum concentration was recorded with no fertilizer, which is similar to our result for the Guder watershed.

5.4.2 In vitro gas production, organic matter digestibility and production of VFAs

The higher GP24 and VFA production in Desmodium plus FYM treatment group compared with control could be due to the better IVOMD and relatively low fiber contents of the former treatment group in both watersheds. Integrated use of FYM and Desmodium increased GP24, IVOMD, and ME of the forage grasses. This might be associated with the higher digestibility in organic matter and lower fiber concentration, indicated by lower ADF in forage grass grown with Desmodium plus FYM compared with control in the Guder watershed, although no such difference was observed in the Aba Gerima watershed. Conversely, Cui *et al.* (2016) showed application of N fertilizer increased crude protein, cellulose, and lignin content by decreasing the energy content available for metabolism and slowing the fermentation rate, as well as decreasing in vitro dry matter disappearance and cumulative gas production. According to the report of Vandermeulen *et al.* (2018), volatile fatty acids are the primary source of metabolizable energy for ruminants; a feed with lower fermentability could elucidate the lower VFA production observed in this study.

Our results are in agreement with those of Heseen *et al.* (2017) who reported that the use of compost alone or combined with mineral fertilizer gave higher GP24 and ME than the use of control for sorghum in the Guder watershed, but no similar finding in ME with Aba Gerima watershed. In addition, Utamy *et al.* (2018) reported increased digestibility due to increased manure application for Napier grass, which agrees with our study. Moreover, similar to our result, Taye Bayble *et al.* (2007) reported higher IVOMD for Napier grown in association with either Desmodium or lablab. The IVOMD values in our study are within the range reported for tropical forages (50% - 80%) (Vandermeulen *et al.*, 2018). The relatively low IVOMD in our Napier grass compared with the report of Tessema Zewdu *et al.* (2002) might relate to our use

of rumen fluid from Japanese Corriedale sheep for in vitro gas production, because ruminants may vary in their composition of rumen microbial inoculum (Zinash Sileshi *et al.*, 1998).

The variations in GP24, IVOMD, and ME between fertilizer treatments, forage grasses, and years were consistent across the agro-ecologies in our study. The lower IVOMD value in the midland versus highland agro-ecology in our study agree with the report by Van Soest (1994) who report that high temperature initiates lignification of cell walls, thereby hindering digestibility of plants. We found that IVOMD was higher with Desmodium plus FYM than FYM in both watersheds, in such case addition of FYM to Desmodium treatment increases the nitrogen supply to the plant by facilitating N₂ fixation by Desmodium. The result of our study is consistent with the report of Van Soest (1994), who reported that an increase in nitrogen supply to plants reduces the structural carbohydrate content, which in turn reduces the proportion of dry matter present as cell wall and improves digestibility. In addition, desho grass grown with Desmodium plus FYM in the second year of production showed higher GP24 and IVOMD as compared to Napier grass in similar treatments in both watersheds (Table 5.3 and 5.4). This might be associated with the lower fiber fraction contents in desho compared with Napier grass, since high fiber content hinders gas production and digestibility (Girma Getachew *et al.*, 2004). The same author indicated that the gas produced reflects the degradation of the sample, the rate and the maximum potential of gas production, and thereby the digestibility of the feed for evaluating the quality of forages which agree with our study.

The effects of the Desmodium plus FYM treatment on TVFAs were consistent across the two watersheds in our study. However, we observed variation in the concentration of TVFA due to type of forage grass and year of production. (Girma Getachew *et al.*, 2004; Khan *et al.*, 2015) reported that differences in in vitro production of VFAs content between grasses present an opportunity for improving the nutritional value of forage. In a study of *Atriplex* (*Atriplex patula*), plantago (*Plantago lanceolata*), and alfalfa (*Medicago sativa*) in Turkey, Kara *et al.* (2016) reported higher concentrations of VFAs, but a similar methane production, to that of the forage grasses tested here. Such variation in VFA concentration among forages is consistent with earlier findings (Dierking *et al.*, 2010; Khan *et al.*, 2015). The high A:Pr ratios observed here for the grasses are in line with the report of (Makkar, 2004) who found that plants with

slowly fermentable carbohydrates like tropical forage grasses yield higher A compared with P. Our observation that the fermentation of the Napier and desho grasses yielded a high A:P ratio of ~2 agrees with the report by Girma Getachew *et al.* (2004), which states that plants with higher levels of structural carbohydrates give higher A:Pr ratios. Consistent with our study, feedstuffs having higher GP24 and IVOMD tend to cause more methane production (Njidda and Nasiru, 2010). Conversely, the VFA and methane production is greatly influenced by the species of ruminant animal and the feeding level (Robinson *et al.*, 2010).

5.4.3 Correlation between chemical composition, IVOMD and VFAs production

The IVOMD of forage grasses were positively affected by ME content, which could explain the significant and strong correlation between digestibility with ME and VFA production. According to the report of Taye Bayble *et al.* (2007) there was a negative correlation between IVOMD and the fiber fraction contents, which agrees with our result. Similar to our result the negative correlation between NDF and GP24 might be related to high NDF and ADF contents, which could be considered to affect microbial activity through reduced availability of fermentable carbohydrates (Njidda and Nasiru, 2010). The relatively strong positive correlation between TVFA production and IVOMD in our study is similar to the finding of Medjekal *et al.* (2018); in our study, there was higher VFA with higher IVOMD under FYM as well as under Desmodium plus FYM compared with the control treatment. The reason for the high IVOMD might be that the relatively higher CP and ME contents of the forage grasses under the integrated treatment improved production of VFA at Guder watershed, and thereby improved the IVOMD of the feed stuffs. We found no significant correlation between IVOMD and methane production, which agree with the report of Robinson *et al.* (2010) in that the weakness of the correlation between VFA concentration and methane production for grazing sheep might be related to changes in rumen volume increasing surface area and VFA absorption. In addition, similar to our result, Melkamu Bezabih *et al.* (2014) reported there were higher associations between IVOMD and ME content in mid rift valley grasslands of Ethiopia. This study found a positive relationship between methane production and fiber fractions (NDF and ADF), which is consistent with previous finding (Singha *et al.*, 2012). On the other hand, Moss *et al.* (2000) discovered a negative relationship between CP and methane production, which is consistent with our findings.

5.5. Conclusions

The forage grasses studied under the various fertilizer treatments varied in IVOMD and VFA production. The chemical composition of forage grasses did not vary in the Aba Gerima watershed, whereas fertilizer treatments influenced CP in the Guder watershed. The CP content achieved in our experiments was higher than the minimum ($70 \text{ g kg}^{-1}\text{DM}$) required for adequate microbial multiplication for proper rumen fermentation. Desmodium plus FYM increased the IVOMD, ME, and TVFA concentrations of Napier and desho grass in both watersheds, and FYM increased the IVOMD concentration in both watersheds, implying that they are suitable as alternative livestock feeds in the study areas and similar agro-ecologies.

CHAPTER 6. BIOMASS YIELD, NUTRITIONAL VALUE, AND SOIL NUTRIENT STATUS OF GRAZING LAND AS INFLUENCED BY FARMYARD MANURE AND ENRICHMENT PLANTING

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Abstract

Grazing land remains the major feed source for livestock for smallholder farmers in Ethiopia, however, its productivity is low and it is prone to degradation. A field experiment was conducted to evaluate the effects of farmyard manure (FYM) and enrichment planting with improved forages on biomass yield, nutritional value, and soil chemical properties in dryland areas of northwestern Ethiopia. The experiment was carried out using a randomized complete block design with three replications for two years. Natural pasture plots were seeded and treated with: Napier grass (*Pennisetum purpureum*) or desho grass (*Pennisetum pedicellatum*), Napier or desho + FYM, Napier or desho + *Desmodium uncinatum* (Desmodium), and Napier or desho

+ FYM + Desmodium; untreated plots were used as controls. In the year 2019, after treatment application the overall herbaceous species identified in the experimental plots were grasses (64%), legumes (22%), and forbs (14%). In all treatment groups, legumes dominate in the first year while grasses in the second year. Within treatment groups, dry matter yield (DMY) increment was recorded from the first year to the second year, by values ranging from 2.9%–23.0%. The mean DMY in the desho + FYM + *Desmodium uncinatum* plots (8.4 t ha⁻¹) was higher ($p < 0.001$) than controls (4.4 t ha⁻¹). Natural pasture treated with Napier or desho in conjunction with either Desmodium or FYM and their combinations had a higher crude protein content ($p < 0.001$) than natural pasture alone. Despite the fact that in vitro organic matter digestibility was higher in desho grass when combined with Desmodium or FYM treatments. Plots treated with Napier + FYM, Napier + Desmodium, and desho + Desmodium + FYM showed organic carbon levels that were significantly higher than controls. Overall, desho + FYM + *Desmodium uncinatum* produced the greatest improvement in grazing land productivity by maintaining soil health.

Key words: Desho grass; Dry land; Dry matter yield; Herbaceous species; Volatile fatty acid

6.1 Introduction

In Ethiopia, livestock is an integral component of most agricultural activities and accounts for 10% of total export earnings, primarily through export of ruminant animals (FAO, 2019). In addition, it contributes 45% of the agricultural gross domestic product (FAO 2019), and 37% to 87% of household income (Behnke and Metaferia, 2013). However, the productivity of livestock farming is low due to a number of constraints, and shortage in both the quality and quantity of feed is an important one of those constraints (Tilahun Amede *et al.*, 2005).

Livestock feed resources in Ethiopia include grazing pasture, crop residue, hay, by-products, improved feed and others (CSA, 2021). Of these, green fodder (grazing; 54.5%) and crop residue (31.1%) are the major feed resources used by livestock holders in rural areas. However, the high rate of human population growth is driving land use conversion, and cropland has increased by 0.4% per year while grazing land has decreased by 3.5% per year (Wuletaw Mekuria *et al.*, 2018). In areas where grazing land is relatively abundant, however, it is restricted to marginal areas with low productivity such as hill tops, swampy areas, and roadsides,

which are overgrazed and unproductive due to continuous heavy grazing and mismanagement (Alemayehu Mengistu, 2004).

Appropriate grazing land management practices can improve herbage yield and quality and ultimately animal productivity. Conant *et al.* (2001) summarized use of different management methods for improving grass lands from 115 studies and reported that fertilization (39%) and native vegetation (15%) are most common, whereas sowing legumes (4%) and grasses (2%) are the least common. However, time of harvest and soil fertility are the main factors that limit biomass yield and nutritive value of pasture lands (Tessema Zewdu *et al.*, 2010b). Different authors (Tessema Zewdu *et al.*, 2010b); Tesfay Atsbha *et al.*, 2020) reported that application of both inorganic and organic fertilizer (manure) increased biomass yield, nutritional value, and botanical composition of natural pasture. However, no research has been conducted on improving grazing land management through integrated use of farmyard manure (FYM) and enrichment planting with improved forages for increased biomass yield, nutritional value, volatile fatty acids, and soil fertility. Thus, the objective of this research was to evaluate the species composition, biomass yield, nutritional value, volatile fatty acid production, and soil fertility improvement of grazing land under FYM and enrichment planting with improved forages.

6.2 Materials and Methods

6.2.1 Description of study area

The research was conducted in the Aba Gerima watershed in the Amhara Region of the upper Blue Nile basin, Ethiopia between April 2019 and December 2020. The Aba Gerima watershed is located in the Bahir Dar Zuria district (37°29'35"E–37°30'52"E", 11°38'51"N–11°40'34"N; 1970 m above sea level; (Fig.6.1). Data from a metrological station at Bahir Dar showed that mean annual rainfall in the Aba Gerima watershed in the 2019 and 2020 cropping seasons was 1786.8 and 1927.4 mm, respectively. Annual mean minimum and maximum temperature were 13.6 °C and 27.6 °C in 2019, and 12.4 °C and 27.5 °C in 2020 (Fig. 6.2).

The main livelihood of farmers in the watershed is mixed crop cultivation and livestock rearing, mainly cattle, sheep, goats, and donkeys (Kindye Ebabu *et al.*, 2019). The major crops grown

in the watershed are finger millet (*Eleusine coracana*), maize (*Zea mays*), and tef (*Eragrostis tef*).

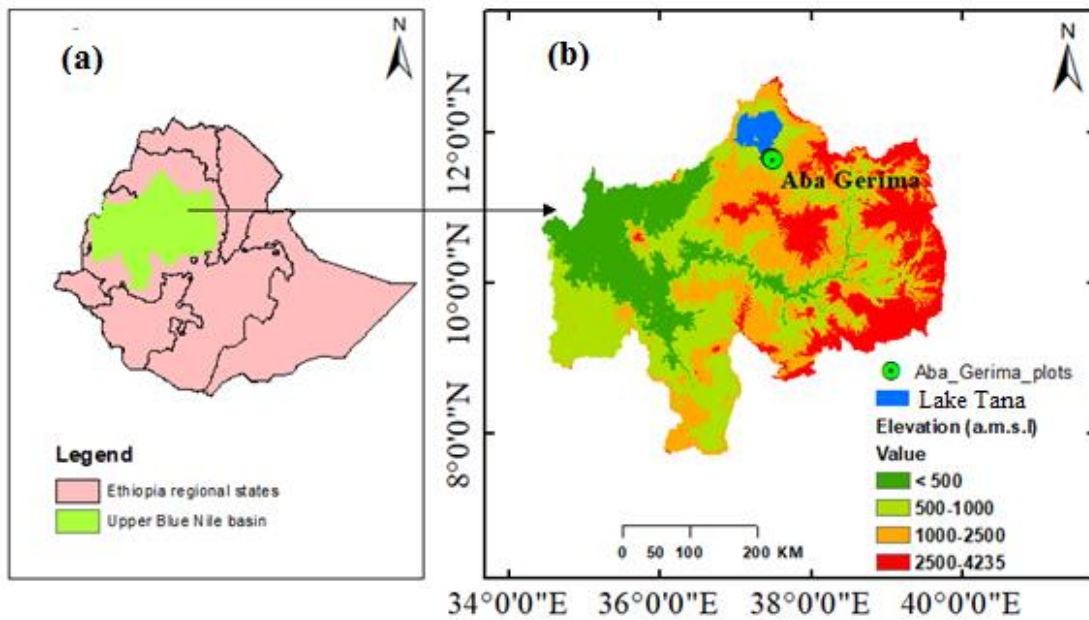


Figure 6.1 Map of the study area. (a) Location of the Upper Blue Nile basin in Ethiopia, (b) Location of the study watershed in the Upper Blue Nile basin.

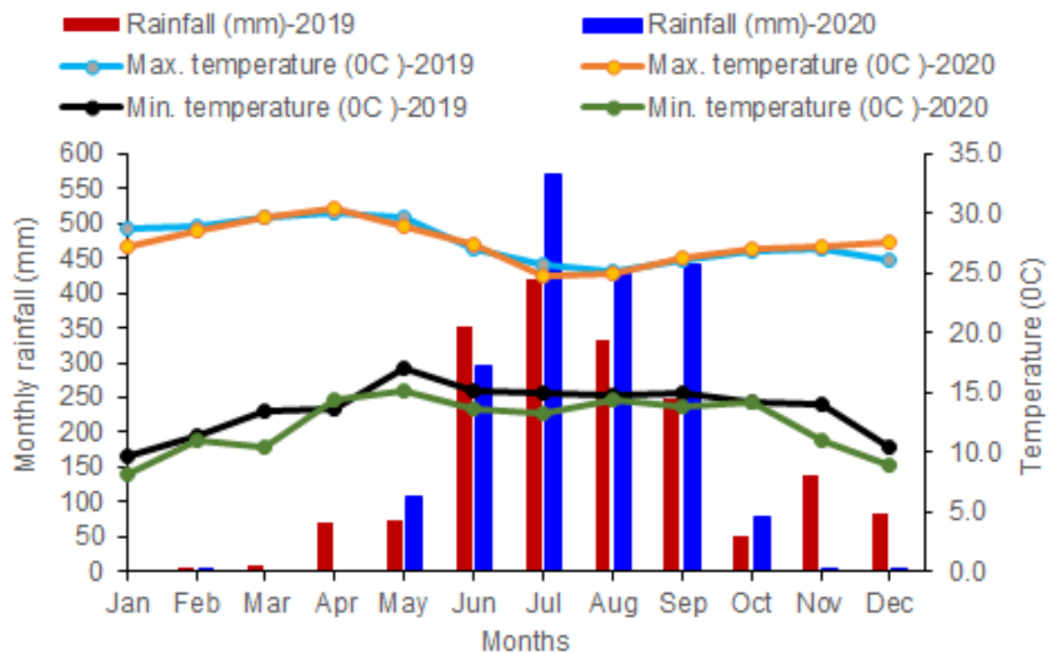


Figure 6.2 Average monthly rainfall and temperature distribution of Aba Gerima watershed (Source: Bahir Dar meteorological station)

6.2.2 Experimental design, plot management, and soil sampling

A 592 m² plot of grazing land was selected and enclosed to prevent animal incursion. We used a randomized complete block design with three replications over two consecutive years. The experimental grazing land was divided into three blocks, each of which comprised nine plots (4 m × 3 m). The nine treatments were natural pasture (NP) alone (control), Napier grass (*Pennisetum purpureum*), desho grass (*Pennisetum pedicellatum*), Napier + FYM, desho + FYM, Napier + Desmodium (*Desmodium uncinatum*), desho + Desmodium, Napier + FYM + Desmodium, and desho + FYM + Desmodium. The inter- and intra-row spacing for Napier was 1 m and 50 cm, respectively, and for desho it was 50 cm for both inter- and intra-row. Desmodium seed was drilled in between rows using minimum soil disturbance in the time of enrichment planting to promote germination.

To minimize soil disturbance, holes for planting forage grasses were made at the beginning of the rainy season, in June, and forage root splits were planted in July (Fig. 6.3a). The FYM used in the experiment was collected at the Bahir Dar University dairy farm, Zenzelma campus, and had the following properties: 47% moisture, pH 7.4, total nitrogen (TN) 1.5%, organic carbon (OC) 17.5%, and available phosphorus (P_{av}) 32.8 mg · kg⁻¹. Farmyard manure was applied at 5 t · ha⁻¹ and mixed with the soil Tesfay Atsbha *et al.* (2020) by hand one month before planting of improved forage grasses. The forage plants used were Napier (*Pennisetum purpureum*) and desho (*Pennisetum pedicellatum*) grasses and the legume *Desmodium uncinatum*, based on



Figure 6.3 Grazing land improvement, plot preparation for enrichment plantation (a) and performance of grazing land after three months of establishment (b)

their adaptability to the areas and potential for natural pasture improvement.

To assess effects on major soil properties, soil samples were taken from each plot with a soil auger at 0–20 cm soil depth before application of treatments in the first year June, 2019 and during biomass data collection in the second year October, 2020. Soil samples were air dried in a shed and crushed with a mortar to pass through a 2-mm sieve for analysis of pH and P_{av} . Samples were sieved through a 0.5-mm mesh size for TN and OC determination. To measure pH, soil samples were mixed 1:2.5 with water and measured with a pH meter (D-51, Horiba, Kyoto, Japan). Total nitrogen analysis was conducted by using the micro-Kjeldahl method (Bremner and Mulvaney, 1982). Organic carbon was determined by the Walkley and Black method (Walkley and Black, 1934). Available phosphorous was determined using the method of Olsen et al. (1954). Exchangeable cations were extracted with 1M ammonium acetate at pH 7.0 with shaking for 1h at 120 rpm and measured by inductively-coupled plasma spectrometry (Thomas, 1982).

6.2.3 Data collection

The vegetation in each plot was sampled using a 1 m $\times$ 1 m quadrat during 50% heading/flowering to quantify biomass yield and botanical composition (Fig. 5.3b). Vegetation was harvested by hand using a sickle, leaving approximately 5-10 cm of stubble height above the ground, and weighed immediately after harvest using a sensitive balance (precision = 0.01 gram). The percent composition of the species in each plot was determined by visual estimation of percentage cover (ILCA, 1990), and the botanical composition of grasses, legumes, and forbs was recorded. At the time of biomass harvest, a 300 g sub-sample was collected, oven-dried at 65 °C for 72 h, and used to determine the dry matter (DM) percentage and for laboratory analysis. The dried samples were ground in a Willey mill, passed through a 1-mm sieve, and stored in airtight plastic containers for subsequent laboratory analysis. The DMY was calculated by multiplying the DM percentage by the green biomass harvested from each sampling area and then extrapolated to $t\ ha^{-1}$. Plant species were identified by experienced personnel using local names in the field. In addition, plants were identified to species on the basis of morphological, structural, and floristic characteristics according to the field guides by (Edwards and Sebsebe, 1997).

6.2.4 Chemical composition, in vitro digestibility, and volatile fatty acid production

Dry matter, ash, and CP were analysed by using the methods of the Association of Official Analytical Chemists (AOAC, 1990) and the EE was analysed using gravimetric methods with ethyl ether. Contents of NDF, ADF, and ADL were assessed following the procedure of Van Soest *et al.* (1991). The syringe method of Menke and Steingass (1988) was used to determine *in vitro* organic matter digestibility (IVOMD). Samples of rumen fluids were collected from two cannulated Japanese Corriedale sheep for measurement of *in vitro* gas production. Briefly, the sheep were fed fresh forage dominated by timothy grass and concentrate mix with free access to water and mineral licks throughout the day. After 3 h of feeding, samples of rumen fluid were collected, flushed with CO₂, strained through two layers of cheesecloth into a prewarmed vessel and kept at 39°C under a continuous flow of CO₂ to be used for *in vitro* fermentation. The IVOMD was estimated on the basis of 24-h gas production (mL) and CP content (g kg⁻¹ DM) by using equation 1, and metabolizable energy (ME, MJ kg⁻¹ DM) content was estimated using GP-24, CP, and EE content by using equation 2 as described by Menke and Steingass (1988):

$$\text{IVOMD (\%)} = 16.49 + 0.9042 \times \text{GP-24} + 0.0492 \times \text{CP} + 0.0387 \times \text{XA} \text{ ----- (1)}$$

$$\text{ME (MJ kg}^{-1}\text{ DM)} = -0.07 + 0.1478 \times \text{IVOMD} - 0.0062 \times \text{XA} \text{ ----- (2)}$$

where GP-24 is the 24-h gas volume (mL 200 g⁻¹ DM), CP is crude protein and XA is EE content, each given as g kg⁻¹ DM of the harvested samples from all treatments.

At the end of *in vitro* gas fermentation, 5 mL of supernatant was centrifuged for 15 min at 4°C. The supernatant was transferred to a 15-mL micro-centrifuge tube to be stored at -20 °C until volatile fatty acids (VFA) analysis. Samples were thawed and filtered to remove foreign materials and the filtered liquid was centrifuged at 10,000 rpm at 4 °C for 30 min. The supernatant (0.5 mL) was used to determine VFA concentrations of acetic, propionic, n-butyric, isobutyric acids by using a gas chromatography machine (Shimadizu Corp., Kyoto, Japan). For the gas chromatography, we used the standard solution, which included 10 mmol L⁻¹ of each of the four acids and 10 mmol L⁻¹ of crotonic acid as the internal standard. The samples were therefore mixed with the internal standard for analysis. By using the determined VFA concentrations, the methane (CH₄) emissions were calculated by using Equation 3, which was developed by (Moss *et al.*, 2000).

6.2.5 Statistical analysis

Data on biomass yield, nutritional value, VFA, and soil chemical properties were subjected to one way analysis of variance (ANOVA) using the general linear model procedure in Statistical Analysis Software (SAS-JMP, 2016). When treatment means showed significant differences, Tukey's honestly significant difference test at $p < 0.05$ was used. The statistical model for data analysis was:

$$Y_{ijk} = \mu + T_i + R_j + \varepsilon_{ijk} \text{ ----- (3)}$$

where Y_{ijk} is the dependent variable (soil chemical properties, biomass yield, chemical composition, and VFA), μ is the overall mean, T_i is treatment effects ($i = 1-9$), R_j is the replication effect, and ε_{ijk} is the residual error.

6.3 Results

6.3.1 Effects of fertilizer treatment on soil chemical properties

The effects of FYM application and enrichment planting on soil chemical properties are presented in Table 6.1. Prior to treatment application, soil chemical properties were pH (5.87), OC (1.57%), TN (0.12%), and P_{av} (8.3 mg kg⁻¹); these were used as baseline soil data. After treatment, the lowest values of OC and TN were observed in controls and in plots with Napier or desho grass; but no significant differences were observed between plots with any other treatments. There was no variation ($p > 0.05$) in pH, P_{av} , Ca, Mg, Na, and K between treatment groups. In plots treated with desho + FYM + Desmodium, soil OC and TN were significantly higher than in controls (46.1% and 38.9% higher, respectively), and P_{av} was 20.4% higher than in controls, although the difference was not significant. Values of most soil chemical properties (pH, OC, TN, and P_{av}) were lower than the critical values from the Ethiopian Soil Information System (EthioSIS).

Table 6.1 Effects of FYM application and enrichment planting on soil chemical properties

Treatments	pH	OC	TN	P _{av} mg kg ⁻¹	Ca	Mg	Na	K
		%						
						Cmol (+) kg ⁻¹		
NP alone (control)	5.81	1.04 ^b	0.11 ^b	6.99	10.86	4.39	0.28	0.33
NP + Napier grass	5.95	1.40 ^{ab}	0.14 ^{ab}	6.35	10.72	4.89	0.32	0.70
NP + Desho grass	5.79	1.33 ^{ab}	0.13 ^{ab}	6.36	9.16	4.00	0.19	0.69
NP + Napier + FYM	5.87	1.96 ^a	0.18 ^a	8.01	8.91	4.43	0.21	0.57
NP + Desho + FYM	5.77	1.70 ^{ab}	0.16 ^{ab}	8.43	10.52	3.94	0.28	0.81
NP + Napier + desm	5.68	1.93 ^a	0.17 ^{ab}	8.69	8.29	3.86	0.24	0.67
NP + Desho + desm	5.71	1.76 ^{ab}	0.16 ^{ab}	9.14	9.90	4.59	0.21	0.73
NP + Napier + desm + FYM	5.67	1.72 ^{ab}	0.16 ^{ab}	9.33	8.76	4.66	0.19	0.53
NP + Desho + desm + FYM	5.77	1.93 ^a	0.18 ^a	8.78	10.06	4.54	0.30	0.58
SEM	0.11	0.15	0.01	0.89	0.90	0.34	0.04	0.16
p-value	0.6981	0.0079	0.0222	0.1776	0.4217	0.4235	0.1588	0.6199
Overall mean	5.78	1.63	0.15	8.01	9.70	4.37	0.25	0.62
Critical values/levels [†]	7.3	3.0	0.20	15	15	2.4	0.3	0.6

[†]Ethiopian Soil Information System; Means with the same superscript in a column are not significantly different at $p < 0.05$ by Tukey's honestly significant difference test; NP: natural pasture; FYM: farmyard manure; desm: *Desmodium uncinatum*; SEM: standard error of mean.

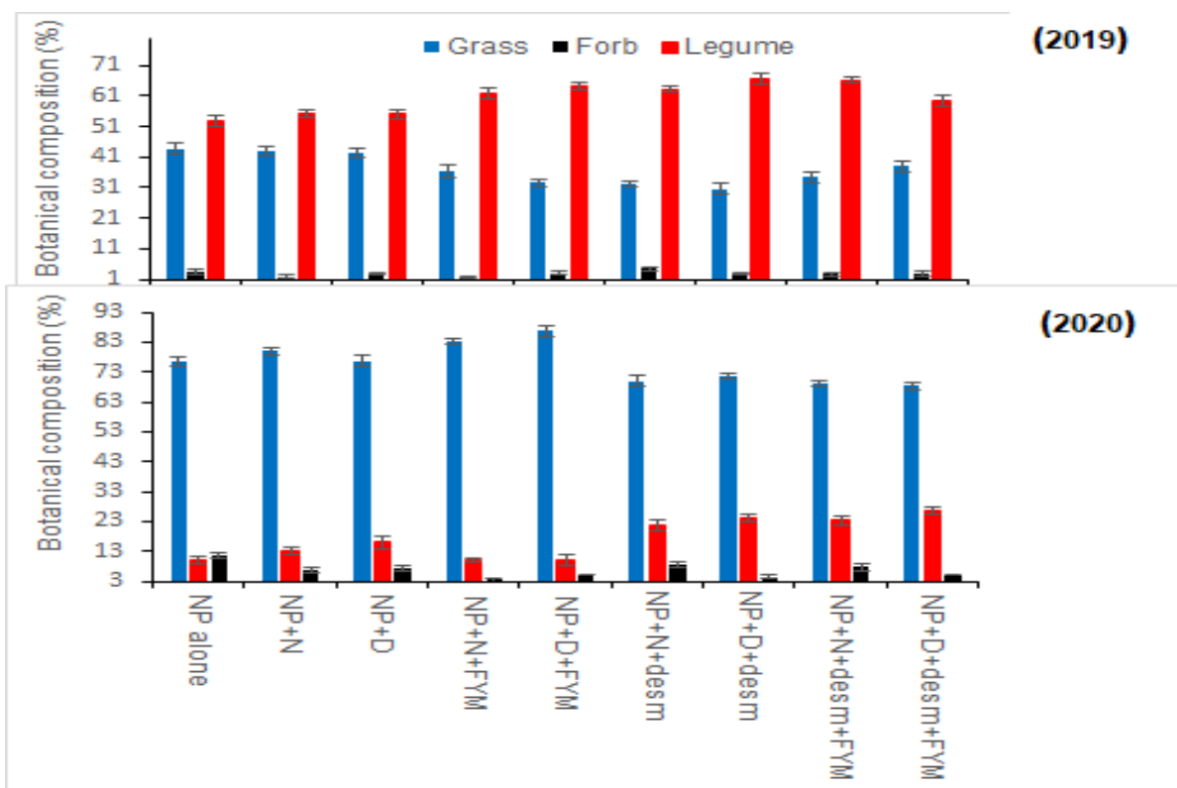
6.3.2 Effects of farmyard manure and enrichment planting on botanical composition

In the first year, we identified 14 herbaceous species in 4 families, including 9 grasses, 3 legumes, and 2 forbs (Table 6.2). Most (9) are perennial and 5 of them are annuals. In most plots grasses such as *Cynodon dactylon* and legumes such as *Trifolium subterraneum* were common. The effects of FYM application and enrichment planting on botanical composition are shown in Fig. 5.4. Plant species composition varied between treatment groups and a higher proportion of grasses was found in Napier or desho + FYM plots and in Napier or desho + FYM + *Desmodium* plots compared to controls. Unlike grasses, the total coverage by legume species composition was consistent across most treatment groups in the first year. In all treatment groups, plots were dominated by legumes in the first year and by grasses in the second year. The proportion of forbs was significantly different in control plots than in other treatment groups.

Table 6.2 Major herbaceous species identified in the experimental grazing land at Aba Gerima watershed

Herbaceous species	Local name	Family	Life history
Grasses			
<i>Cynodon dactylon</i>	Serdo	Poaceae	Perennial
<i>Arthraxon prionodes</i>	Yekoksar	Poaceae	Perennial
<i>Eleusine indica</i>	Yewusha dagusa	Poaceae	Annual
<i>Pennisetum pedicellatum</i>	Desho	Poaceae	Perennial
<i>Andropogon abyssinicus</i>	Gaja	Poaceae	Perennial
<i>Pennisetum purpureum</i>	Napier	Poaceae	Perennial
<i>Pennisetum macrourum</i>	Tucha	Poaceae	Perennial
<i>Digitaria abyssinica</i>	Wariat	Poaceae	Annual
<i>Sporobolus pyramidalis</i>	Murie	Poaceae	Perennial
Legumes			
<i>Trifolium subterraneum</i>	Wazima	Fabaceae	Annual
<i>Desmodium uncinatum</i>	<i>Desmodium</i>	Fabaceae	Perennial
<i>Launaeain fybacea</i>	Mechie	Fabaceae	Annual
Forbs			
<i>Persicaria attenuata</i>	Wuha anqur	Polygonaceae	Annual
<i>Guizotia scabra</i>	NI	Asteraceae	Perennial

NI = Not identified



D: Desho; desm: *Desmodium uncinatum*; FYM: farmyard manure; N: Napier; NP: natural pasture

Figure 6.4 Percentage botanical composition of grazing land under FYM and enrichment plantation with improved forages for 2019 and 2020 production years.

6.3.3 Effects of FYM and enrichment planting on dry matter yield and chemical composition

The effects of FYM application and enrichment planting on DMY and chemical composition are shown in Table 6.3. The dry matter yield differed significantly between treatment groups in 2019, in 2020, and on average. In addition, DMY was significantly higher ($p < 0.001$) in desho + FYM + Desmodium plots in both years. However, DMY was significantly lower in control plots than in all other treatments in both years and their average. Similarly, enrichment plantation with either Napier or desho grass alone showed lower biomass yield than plots treated with FYM or with FYM + Desmodium in both years. Within treatment groups, yield increased from the first year to the second year, by values ranging from 3%–24.1%. The greatest change in biomass yield between years was recorded in desho + FYM and in Napier or desho + FYM + Desmodium plots, with smaller changes in controls, and in plots with Napier + Desmodium.

The 20% increase in biomass yield in the control plots was likely caused by fencing to prevent animal incursion. The desho + FYM + *Desmodium* plots showed DMY increments of 50.6% and 45.5% compared to controls in 2019 and 2020 harvesting years, respectively.

Table 6.3 Biomass yield and chemical composition of natural pasture under FYM and enrichment planting at Aba Gerima watershed

Treatments	DMY (t ha ⁻¹)			Chemical composition (% DM)				
	2019	2020	Mean	CP	Ash	NDF	ADF	ADL
NP alone (control)	4.0 ^e	4.8 ^d	4.4 ^f	9.0 ^c	6.6	64.1	37.6	8.4
NP + Napier	5.4 ^d	6.5 ^c	5.9 ^e	9.4 ^c	6.0	63.9	35.6	7.9
NP + Desho	5.8 ^{cd}	7.2 ^{bc}	6.5 ^e	9.0 ^c	6.3	66.6	39.0	8.7
NP + Napier+ FYM	7.3 ^{ab}	7.7 ^{abc}	7.5 ^{bc}	9.6 ^{bc}	6.2	64.9	40.9	9.5
NP + Desho + FYM	7.9 ^a	8.5 ^{ab}	8.2 ^{ab}	9.5 ^{bc}	6.3	62.3	39.6	9.4
NP + Napier+ desm	6.7 ^{bc}	6.9 ^c	6.8 ^{cde}	10.6 ^{ab}	6.0	63.6	38.3	8.2
NP + Desho + desm	5.7 ^{cd}	7.4 ^{bc}	6.6 ^{de}	10.0 ^{bc}	6.4	61.9	41.1	9.1
NP + Napier + desm + FYM	7.2 ^{ab}	7.7 ^{abc}	7.4 ^{bcd}	11.4 ^a	6.2	60.8	39.8	9.0
NP + Desho + desm + FYM	8.1 ^a	8.8 ^a	8.4 ^a	10.6 ^{ab}	6.4	60.3	36.7	8.1
SEM	0.24	0.26	0.18	0.23	0.22	1.94	2.29	0.81
<i>p</i> -value	<.0001	<.0001	<.0001	<.0001	0.6237	0.4147	0.7211	0.8306
Overall mean	6.5	7.3	6.9	9.9	6.3	63.2	38.7	8.7

Means with the same superscript in a column is not significantly different at $p < 0.05$; DMY: dry matter yield; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; ADL: acid detergent lignin.

Plots treated with Napier + Desmodium, Napier + FYM + Desmodium, and desho + FYM + Desmodium showed significantly higher CP ($p < 0.001$) than controls, Napier or desho treatments. However, there was no significant difference between controls and Napier or desho grass treated plots. On the other hand, CP content did not show significant variation between Napier or desho + Desmodium and the Napier or desho + FYM + Desmodium treatment groups.

6.3.4 Effects of FYM application and enrichment planting on in vitro digestibility and volatile fatty acid production

The effects of FYM application and enrichment planting on in vitro digestibility and VFA production are shown in Table 6.4. Plots with desho + FYM + Desmodium as well as those

with either Napier or desho grass + FYM showed higher ($p < 0.01$) GP, IVOMD, and ME compared to control and desho plots. However, Napier or desho + FYM or Napier or desho + Desmodium + FYM did not show significant variation in their GP, IVOMD, and ME contents.

Table 6.3 Gas production, IVOMD, ME, and VFA production under fertilizer treatments and enrichment planting at Aba Gerima watershed

Treatments	GP (mL 0.2 g ⁻¹ DM)	IVOM D (%)	ME (MJ kg ⁻¹)	Aetate (mmol L ⁻¹)	Propionate (mmol L ⁻¹)	Butyrate (mmol L ⁻¹)	Valerate (mmol L ⁻¹)	TVFA (mmol L ⁻¹)
NP alone (control)	36.0 ^b	56.2 ^b	7.8 ^b	58.1 ^{ab}	30.0	6.6 ^{ab}	1.3 ^b	97.1
NP + Napier grass	42.2 ^{ab}	62.3 ^{ab}	8.7 ^{ab}	58.3 ^{ab}	27.1	5.3 ^{ab}	1.6 ^b	92.2
NP + Desho grass	36.3 ^b	56.4 ^b	7.9 ^b	53.4 ^b	27.3	5.8 ^{ab}	1.8 ^{ab}	88.4
NP + Napier + FYM	44.5 ^a	63.4 ^a	9.0 ^a	55.2 ^b	28.7	7.9 ^a	2.1 ^{ab}	93.8
NP + Desho + FYM	44.7 ^a	64.0 ^a	9.0 ^a	55.2 ^b	27.5	7.6 ^{ab}	2.2 ^{ab}	92.5
NP + Napier + desm	39.5 ^{ab}	59.7 ^{ab}	8.4 ^{ab}	57.0 ^{ab}	29.9	6.2 ^{ab}	1.8 ^{ab}	94.9
NP + Desho + desm	44.0 ^a	63.7 ^a	8.9 ^{ab}	53.5 ^b	28.5	4.4 ^b	1.2 ^b	87.7
NP + Napier + desm + FYM	41.6 ^{ab}	62.1 ^{ab}	8.7 ^{ab}	57.8 ^{ab}	29.5	6.4 ^{ab}	1.5 ^b	95.2
NP + Desho + desm + FYM	44.2 ^a	63.4 ^a	8.9 ^a	62.2 ^a	31.0	7.1 ^{ab}	2.8 ^a	102.2
SEM	1.42	1.26	0.19	1.59	1.15	0.65	0.23	3.06
<i>p</i> -value	0.0015	0.0011	0.0011	0.0276	0.2620	0.0345	0.0047	0.1034
Overall mean	41.4	61.3	8.6	56.8	28.8	6.4	1.8	93.8
CV	6.0	3.6	3.8	4.9	6.9	7.8	9.1	5.7

Means with the same superscript in a column is not significantly different at $p < 0.05$; desm: *Desmodium uncinatum*; FYM: farmyard manure; GP: gas production; IVOMD: *in vitro* organic matter digestibility; ME: metabolizable energy; TVFA: total volatile fatty acid; CV: coefficient of variation.

Acetic acid levels were higher ($p < 0.05$) in the desho + FYM + Desmodium plots compared to the Napier or desho + FYM plots. Conversely, the total VFA concentration followed the trend for propionic acid and no difference ($p > 0.05$) was recorded between treatment groups. With addition of FYM and enrichment planting, Volatile fatty acid levels showed few significant differences between treatments, ranging from 53.4–62.2 mmol L⁻¹ for acetic acid, from 27.1–31.0 mmol L⁻¹ for propionic acid, from 4.4–7.9 mmol L⁻¹ for butyric acid, and from 1.2–2.8 mmol L⁻¹ for valeric acid. Concentrations of valeric acid is significantly higher in the desho +

Desmodium + FYM plots than in four other treatment groups, and that butyric acid is higher in the Napier + FYM plots than in the desho + Desmodium plots.

6.4 Discussion

6.4.1 Soil chemical properties

We found that application of FYM and planting of improved forage improved soil chemical properties to varying degrees (Table 6.1). Differences in OC, TN, and P_{av} between treatments might be due to application of FYM and *Desmodium uncinatum* which increase nutrient availability. The soil in all treatment groups could be classified as moderately acidic pH, very low OC, low TN, and very low P_{av} (EthioSIS, 2013). The moderately acidic pH (5.67 to 5.95) of our soil makes it suitable for growth of tropical forages. According to Tekalign Tadese (1991), the TN content of most treatment groups in our study is moderate, indicating that it will need continued attention to maintain sufficient levels of this critical nutrient for sustainable herbage production. Available P is low (Tekalign Tadese, 1991), perhaps owing to continuous overgrazing and mismanagement of natural pasture; addition of P is required for sustainable forage production.

The application of FYM to crop land improves soil OM, TN, dissolved OC, and NH_4^+ contents (Utamy *et al.*, 2018; Ma *et al.*, 2020), and we found similar result in our study. These authors stated that FYM could replace chemical fertilizer, which is expensive for resource-poor Ethiopian smallholder farmers. In addition, the higher OC, TN, and P_{av} in the FYM and enrichment planting groups was linked with improved biomass production (Table 6.3) and soil fertility. This result may be due to addition of organic matter to the soil leading to availability of nutrients vital to plant growth, thereby improving biomass yield. Our results suggest that enrichment planting positively influences the OC content of grazing land soil, concordant with the report of Conant *et al.* (2001) in that planting improved forage and sowing legumes increases soil carbon storage in grassland. On the other hand, Tessema Zewdu *et al.* (2011), reported increased total N concentrations under light grazing in an Ethiopian semi-arid savanna. The author stated that the reason could be due to the availability of organic material, higher standing biomass, and nutrient export via grazing at heavy grazing sites. Furthermore, the same

author demonstrated that heavy grazing reduced soil quality, resulting in decreased growth, diversity, abundance, aboveground standing biomass, and basal cover of herbaceous species.

6.4.2 Herbaceous species and botanical composition

The Ethiopian highlands have rich variety of pasture species, particularly indigenous grasses and legumes (Tessema Zewdu 2003b; Yihalem Deneke *et al.*, 2005); however, we observed less herbaceous species than Yihalem Deneke *et al.* (2005) or Tesfaye Desalew *et al.* (2010) reported in north western Ethiopia. The variation observed might be related to overgrazing, soil, climate disparity, management methods, or sampling area size. The presence of desirable perennial and annual grasses such as *Cynodon*, *Digitaria*, *Pennisetum*, *Andropogon*, *Eleusine*, and *Arthraxon* species in the study area would indicate improvement of NP by FYM application and enrichment planting. According to the report of (Yihalem Deneke *et al.* 2005; Tessema Zewdu *et al.* 2010b), these species are highly resilient against the rigors of drought, frost, and high grazing pressure.

The relatively higher proportion of grasses in our study under FYM (Fig. 6.4b) might be due to the increased nitrogen provided by FYM which allowed grasses to outcompete the legumes (Tesfaye Atsbha *et al.*, 2020). However, the proportion of legumes was relatively higher in *Desmodium* and FYM + *Desmodium* plots in the second year, perhaps because the prevalence of the legume *Desmodium uncinatum* in these treatment groups increased the proportion of legumes. Fekadu Nemera *et al.* (2017) reported a higher proportion of legumes under cattle manure and wood ash, which contradicts our finding. Similar to our study, Tesfaye Atsbha *et al.* (2020) and Shiferaw Yalew *et al.* (2020) reported a higher proportion of forbs in the unfertilized (control) treatment group. The higher proportion of grasses and the lower proportion of legumes in the second year (Fig. 6.4) might also be linked to suppression caused shading by natural and enriched forage grasses. On the other hand, grasses may be stronger competitors for available nitrogen, permitting an increased rate of growth, leaf expansion, and tillering, followed by suppression of the legumes by shading (Miles and Manson, 2000).

6.4.3 Biomass yield and chemical composition of natural pasture

The total biomass yield in our natural pasture was greater than previously reported values (Yihalem Denekew *et al.*, 2005; Tesfay Atsbha *et al.* 2020) for Ethiopian grazing lands. This might be associated with variation in soil properties, climate, and the nature of the treatments used in the experiment. Conversely, other authors (Tessema Zewdu *et al.*, 2010b; Shiferaw Yalew *et al.*, 2020) reported comparable dry matter yield and CP content with application of organic and inorganic fertilizers under similar agro-ecology. The relatively better biomass yield in plots with either forage grass + FYM or FYM + Desmodium might be associated with increased availability of essential soil nutrients from both FYM and the legume Desmodium for plant growth (Table 6.1). Plots with desho + FYM + Desmodium gave a substantial yield improvement (102.5%) over controls; this improvement is greater than that reported previously (Adane Kitabe and Berhan Tamir, 2005; Tessema Zewdu *et al.*, 2010b). Thus, we infer that the increased productivity of natural pastures in our study could be due to improvement of soil chemical properties, especially OM, OC, and TN (Table 6.1), by application of FYM or FYM + Desmodium.

The higher biomass yield in 2020 than in 2019 might be associated with the slight increase in rainfall beginning in May (Fig. 6.2). In addition, the area was protected from free grazing, allowing it to be enriched with soil organic matter and for the seed bank to increase, and the additive effects of FYM as well as its combination with Desmodium. Enrichment planting can have persistent effects, as the improved forages become established in the grazing land. In general, production of greater DMY with better nutritive value by enrichment planting with desho + FYM + Desmodium could be a good strategy in areas where mixed crop livestock production systems are implemented.

In all treatment groups the CP content was above the 7% required for the normal functioning of rumen microorganisms (Van Soest, 1994). The high CP content might be associated with the high proportion of legumes such as *Trifolium subterraneum* in all treatment groups. Farmers near the study area might be able to meet the need for this critical nutrient, but supplementation with other protein-rich feed is required for optimal production. Consistent with our results, Fekadu Nemera *et al.* (2017) reported that the CP content of natural pasture was increased by addition of cattle manure. Similar to the report of Tessema Zewdu *et al.* (2010b), we found that

the CP content of control in the first year was comparable, might be linked with higher proportion of legumes in all treatment groups. In addition, Tessema Zewdu *et al.* (2010b) also stated that the higher CP in unfertilized plots might be due to an increased proportion of legumes in the pasture (Fig. 6.4b), since legumes contain a high CP content. In addition, Shehu and Akinola (1995) reported that legumes made a strong contribution to maintaining the CP content of grass–legume mixed pastures and that CP content decreases with advancing stages of growth of the plant.

No variation was observed between treatment groups in fiber fractions (NDF and ADF), and the mean values reported here were lower than those in Bimrew Asmare *et al.* (2017), who studied desho grass under different harvesting dates and agro-ecologies. The variation might be associated with differences in management system, soil properties, or climate. Conversely, our NDF value was comparable with values reported for (Yihalem Denekeew *et al.* 2005; Tessema Zewdu. *et al.* 2010b) natural pasture harvested at 70 to 90 days in similar agro-ecologies. The NDF content in our study was above the critical level ($600 \text{ g kg}^{-1} \text{ DM}$) for voluntary dry matter intake and feed conversion efficiency (Meissner *et al.* 1991). However, our fiber content was lower than the $700\text{--}750 \text{ g kg}^{-1} \text{ DM}$ maximum cell wall concentration that decrease feed intake and animal performance in beef animals (Buxton, 1996). Thus, the fiber content of the herbage in our natural pasture plots might not affect the feed intake of cattle for better production.

6.4.4 In vitro organic matter digestibility and volatile fatty acid production

Gas production and in vitro organic matter digestibility showed similar trends in desho, desho + FYM, and desho + FYM + Desmodium integrated treatment groups, which implies that feed with a higher GP is better digestible by ruminant animals (Girma Getachew *et al.* 2004). The concentrations of acetic acid were comparable, those of propionic acid were slightly higher, and those of butyric acid were lower than those reported by Burke *et al.* (2006) for fresh tropical and temperate forages. In addition, Burke *et al.* (2006) reported a higher VFA concentration for legumes but a lower concentration for tropical forage grasses. Consistent with our results, Medjekal *et al.* (2018) reported lower GP associated with lower fermentability of the substrate, which results in lower methane production. Thus, we found that a relatively higher DMY was accompanied by better IVOMD and total VFA production in desho + FYM + Desmodium plots,

suggesting that this treatment could provide an advantage for smallholder farmers engaged in dairy production in the study areas.

Limitation of the study

The limitation of the study is unable to address socioeconomic data for cost and sustainability of farmyard manure application on improved forage production and natural pasture improvement. Hence, future research should focus on cost-benefit analysis so that livestock producers can make decisions about forage production from different feed sources.

6.5 Conclusions

We found that the natural pasture was dominated by grasses followed by legumes and finally by forbs. In the first year, plots were dominated by legumes, whereas the proportion of grasses was higher in the second year. Application of farmyard manure and enrichment planting with improved forages improved soil organic carbon level, biomass yield, *in vitro* organic matter digestibility, and volatile fatty acid production of natural pasture. Enrichment planting with desho grass showed better compatibility, biomass yield, and nutritional value than the other forage plants in natural pasture. Thus, we recommend addition of desho grass + farmyard manure + *Desmodium uncinatum* as first option and desho grass + farmyard manure as alternative management strategy for improvement of grazing land by maintaining soil health in the study area and similar agro-ecologies.

CHAPTER 7. SUMMARY, CONCLUSION AND RECCOMENDATION

7.1 Summary and conclusions

The first field experiment focused on producing a higher biomass yield with quality forage grasses under farmyard manure and *Desmodium intortum* intercropping management system in the midland and highland agro-ecologies of Upper Blue Nile basin, Ethiopia. Thus, the first experiment was designed specifically to (i) determine the effect of farmyard manure and Desmodium integration on forage grass growth characteristics, dry matter yield, and crude protein yield, as well as its effects on soil physicochemical properties (first article); and (ii) investigate the chemical composition, in vitro gas production, volatile fatty acid, and methane production of Napier and desho grass. We attempted to assess the impact of farmyard manure application and enrichment planting on biomass yield, botanical composition, chemical composition, in vitro gas production, and soil fertility in degraded natural pasture lands in the second experiment.

First experiment,

Farmyard manure and *Desmodium intortum* integration influence the growth and biomass yield of Napier and desho grass in midland and highland agro-ecologies. When compared to the control and with Desmodium treatments, the morphological characteristics (plant height, leaf length, and number of tillers per plant) of Napier grass and desho grass were significantly improved in both FYM and the combined use of FYM and Desmodium treatments. In the two agro-ecologies, Napier and desho grass with FYM and combined use of FYM and Desmodium yielded more dry matter and crude protein than controls. In addition, Napier grass and desho grass with FYM and combined use of Desmodium and FYM treatments showed SOC (18.4% and 20.5%), TN (15.4%) and Pav (16.3% and 23.0%) higher than forage grass alone. The finding of this research will enable to combat feed scarcity in terms of quality and quantity for improved animal production in environmentally friendly production systems.

The EE content of the FYM and Desmodium + FYM fertilizer treatments increased by 14.4-17.9% in the Aba Gerima watershed when compared to the control in Napier grass, whereas desho grass did not show an increase in the same fertilizer treatments. In the same watershed,

fertilizer treatments had no effect on the CP content of Napier or desho grass, but variation was observed in the Guder watershed. The CP content obtained in our study was higher than the minimum (70 g kg⁻¹ DM) required for adequate microbial multiplication for proper rumen fermentation. In the same watershed, the NDF content of FYM and Desmodium plus FYM fertilizer treatments increased by 6.5% in Napier grass, while desho grass decreased by 6.0% and 3.9%, respectively. The fiber fraction values in the control treatment were higher than in the other fertilizer treatments, but this difference was only significant for ADF (control versus FYM; control versus Desmodium plus FYM). In Aba Gerima, the *Desmodium intortum* plus FYM treatment increased IVOMD (6.7 vs. 4.7%), metabolizable energy (5.5 vs. 4.5%), and VFA production (23.1 vs. 3.0%). In Guder, on the other hand, IVOMD (13.7 vs 4.6%), metabolizable energy (13.3 vs 3.3%), and VFA production (11.2 vs 5.6%) showed increment in the same treatment for Napier grass and desho grass than in the control. In vitro organic matter digestibility also had a significant and strong positive correlation with ME ($r = 0.999$, $P < 0.001$), as well as a significant and moderate correlation with TVFA ($r = 0.741$, $P < 0.05$). *Desmodium intortum* plus FYM treatments improve the nutritional value, IVOMD, and VFA production of Napier and desho grasses in dryland areas of the Upper Blue Nile basin, facilitating their growth as alternative livestock feed for better production in these areas.

Second experiment

Generally, we found that the natural pasture was dominated by grasses, followed by legumes, and finally by forbs. Plots with natural pasture alone recorded lower biomass yield than with FYM and enrichment planting either with Napier or desho grass. In the studied natural pastures, grasses such as *Cynodon dactylon* and legumes such as *Trifolium subterraneum* were common. In plots treated with desho + FYM + Desmodium, soil OC and TN were higher than in controls (46.1% and 38.9% higher, respectively), and Pav was 20.4% higher than in controls.

In comparison to the controls (natural pasture alone), the desho + FYM, Napier, and desho + FYM + *Desmodium uncinatum* treatments yielded the highest biomass yield. Plots treated with Napier + Desmodium, Napier + FYM + Desmodium, and desho + FYM + Desmodium had higher CP than controls, and Napier, or desho treatments. Plots with desho + FYM +

Desmodium, as well as those with Napier or desho grass + FYM, had significantly higher ($P < 0.001$) GP, IVOMD, and ME than control. The levels of volatile fatty acids in the different treatments ranged from 53.4-62.2 mmol L⁻¹ for acetic acid, 27.1-31.0 mmol L⁻¹ for propionic acid, 4.4-7.9 mmol L⁻¹ for butyric acid, and 1.2-2.8 mmol L⁻¹ for valeric acid. As a result, we recommend for the integration of desho grass + farmyard manure + *Desmodium uncinatum* or desho + farmyard manure to improve grazing land by maintaining soil health in this area and similar agro-ecologies.

7.2 Recommendations

This thesis research provides useful information for livestock producers, primarily smallholder farmers and investors, on the concept of managing improved forages (Desmodium intercropping and farmyard manure application) and their respective benefits in sustainable forage production under environmentally friendly production systems. On the other hand, grazing land should receive due attention for improved biomass yield and nutrition as its contribution to livestock feed is immense in the country.

First, the results from our study revealed that the growth characteristics and yield of Napier and desho grass are not as expected for intensive livestock production. Taking this into account, additional research on Napier grass and desho grass integrated with Desmodium by using organic and inorganic fertilizer sources for higher yields over longer periods of time under diversified agro-ecologies due attention. Second, for improved animal production, further studies on the effects of the feed package selected on animals will be expected with Napier and Desho grass.

Third, we recommend combining desho grass with farmyard manure plus Desmodium uncinatum or desho grass with farmyard manure to improve grazing land productivity by maintaining soil health in this area and similar agro-ecologies to combat a lack of quality and quantity feed for sustainable livestock production. As a result, it is preferable to test such treatments in different grazing lands with diverse agro-ecologies.

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APPENDIX

LIST OF APPENDIX TABLES

Appendix Table 4.1 Pearson correlation coefficients among morphological, yield, and soil properties

Parameters	DMY	CP	CPY	PH	LL	LW	NTPP	LSR	pH	TN
DMY	1									
CP	-0.17*	1								
CPY	0.92**	0.12ns	1							
PH	0.54**	0.10ns	0.56*	1						
LL	0.40**	0.14ns	0.42**	0.91**	1					
LW	0.48**	0.11ns	0.51**	0.88**	0.79**	1				
NTPP	0.55**	-0.47**	0.37**	-0.15ns	-0.24**	-0.27*	1			
LSR	-0.03ns	0.20**	0.09ns	0.35**	0.29**	0.45**	-0.11ns	1		
pH	0.66**	-0.39**	0.57*	0.30*	0.07ns	0.32**	0.53**	0.16ns	1	
TN	-0.13ns	0.53**	-0.01ns	-0.14ns	0.06ns	-0.28*	-0.09ns	-0.05ns	-0.58**	1

Numbers with the same superscript within a column are not statistically different ($p < 0.05$); *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$; ns: not significant

Appendix Table 4.2 Mean dry matter yield by frequency of harvest under various fertilizer treatments at Aba Gerima watershed

Treatments	Dry matter yield (t ha ⁻¹) for various harvests					
	1	2	3	4	5	6
Desho alone	2.4±0.15	2.3±0.35	1.8±0.26	-	-	-
Desho + desm	2.6±0.66	2.9±0.73	2.7±0.84	-	-	-
Desho + FYM	3.5±0.32	4.3±0.25	4.4±0.27	-	-	-
Desho + FYM + desm	3.9±0.24	3.3±0.17	3.5±0.20	-	-	-
Napier alone	1.1±0.01	1.4±0.13	1.5±0.11	2.1±0.10	2.6±0.21	2.2±0.26
Napier + desm	1.2±0.18	1.3±0.10	1.4±0.03	2.3±0.31	2.6±0.17	1.9±0.19
Napier + FYM	2.0±0.23	2.0±0.17	2.1±0.18	3.8±0.16	3.7±0.32	2.4±0.15
Napier + FYM + desm	1.6±0.15	2.1±0.18	2.2±0.21	3.6±0.23	3.9±0.21	2.5±0.26
Mean	2.3	2.5	2.5	2.9	3.2	2.3

Appendix Table 4.3 Mean dry matter yield by frequency of harvest under various fertilizer treatments at Guder watershed

Treatments	Dry matter yield (t ha ⁻¹) for various harvests				
	1	2	3	4	5
Desho alone	1.4±0.21	3.2±0.71	4.0±0.75	-	-
Desho + desm	1.6±0.32	3.2±0.95	3.5±0.76	-	-
Desho + FYM	2.2±0.20	5.6±1.05	4.5±0.80	-	-
Desho + FYM + desm	2.5±0.24	4.3±0.29	5.6±0.39	-	-
Napier alone	1.1±0.07	1.5±0.20	1.4±0.25	2.5±0.19	2.1±0.33
Napier + desm	0.7±0.08	1.6±0.14	2.0±0.05	2.6±0.04	2.1±0.29
Napier + FYM	1.5±0.08	1.7±0.18	2.7±0.08	3.6±0.12	2.0±0.29
Napier + FYM + desm	1.2±0.09	1.7±0.20	2.8±0.32	3.4±0.32	2.2±0.18
Mean	1.5	2.8	3.3	3.0	2.1

FYM: farmyard manure; desm: *Desmodium intortum*

Appendix Table 4.4 Results of Tukey's tests exploring the interaction effects of forage grasses by fertilizer treatments on growth characteristics and yield at Aba Gerima

Factors		DMY	CP	CPY	PH	LL	LW	NTPP	LSR
F	FS	t ha ⁻¹	g kg ⁻¹	kg ha ⁻¹	cm			plant ⁻¹	
Control	Napier	7.4	95.0	748.1 ^b	100.2	72.3	2.8 ^a	32.9 ^d	2.2
Control	Desho	4.3	75.0	325.3 ^d	42.6	25.0	1.3 ^b	80.4 ^c	1.6
Desmodium	Napier	7.5	85.3	704.7 ^{bc}	97.0	72.4	2.7 ^a	31.8 ^d	2.2
Desmodium	Desho	4.7	71.8	504.8 ^{cd}	47.1	26.9	1.5 ^b	87.5 ^{bc}	1.7
FYM	Napier	11.1	89.9	998.4 ^a	102.8	75.0	2.9 ^a	38.3 ^d	2.3
FYM	Desho	8.1	66.6	526.1 ^{bcd}	54.2	31.1	1.5 ^b	107.2 ^{ab}	1.5
Desmo + FYM	Napier	10.9	94.9	1100.1 ^a	104.2	75.8	2.9 ^a	38.3 ^d	2.4
Desmo + FYM	Desho	7.2	64.1	517.6 ^{bcd}	58.7	33.3	1.6 ^b	112.5 ^a	1.6
Overall mean		7.7	80.3	678.1	75.9	51.5	2.2	66.1	1.9
SEM		0.365	4.26	51.43	2.25	1.27	0.060	5.07	0.091
P-values		0.6871	0.2530	0.0066	0.0685	0.2791	<.0001	0.0511	0.3451

Appendix Table 4.5 Results of Tukey's tests exploring the interaction effects of forage grasses by fertilizer treatments on growth characteristics and yield at Guder watershed

Factors		DMY	CP	CPY	PH	LL	LW	NTPP	LSR
F	FS	t ha ⁻¹	g kg ⁻¹	kg ha ⁻¹	cm			plant ⁻¹	
Control	Napier	4.6 ^c	131.9	597.2	85.1 ^a	69.2	2.2	28.0	2.3
Control	Desho	4.2 ^c	91.9	311.2	37.5 ^c	22.6	1.3	88.6	1.8
Desmodium	Napier	5.1 ^{bc}	126.3	662.8	87.1 ^a	70.3	2.1	27.6	2.2
Desmodium	Desho	4.4 ^c	91.3	333.8	37.1 ^c	21.0	1.4	87.9	2.0
FYM	Napier	6.5 ^{ab}	135.2	962.1	93.4 ^a	72.8	2.3	32.5	2.3
FYM	Desho	7.5 ^a	108.1	771.3	47.4 ^b	27.5	1.5	102.4	2.0
Desmo + FYM	Napier	6.3 ^{ab}	133.8	959.3	87.1 ^a	70.4	2.2	34.6	2.3
Desmo + FYM	Desho	7.8 ^a	101.7	625.6	48.8 ^b	26.7	1.4	110.2	1.9
Overall mean		5.8	115.0	652.9	65.4	47.6	1.8	64.0	2.1
SEM		0.361	4.07	56.6	2.12	1.34	0.058	5.02	0.086
P-values		0.0118	0.4618	0.5672	0.0497	0.2300	0.7337	0.3609	0.2648

Values within a column that bear the same letter are not statistically different ($p < 0.05$); FS: forage species; F: fertilizer treatments. DMY: dry matter yield; CP: crude protein; CPY: crude protein yield; PH: plant height; LL: leaf length; LW: leaf width; NTPP: number of tillers per plant; LSR: leaf-to-stem ratio.

Appendix Table 5.1 Effects of fertilizer treatment on in vitro organic matter digestibility and volatile fatty acid production at Aba Gerima

Variables	GP24	IVOMD	ME	VFAs and methane production (mmol L ⁻¹)						
	ml/0.2g DM	%	MJ/kg DM	Acetate	Propionate	Butyrate	Valerate	TVFA	A: Pr	CH ₄
<i>Fertilizer treatment (F)</i>										
Control	31.9 ^c	52.6 ^c	7.3 ^b	53.6 ^c	27.5 ^c	6.3 ^b	3.0 ^a	90.3 ^b	2.0 ^b	20.5 ^b
Desm	32.9 ^{bc}	53.2 ^{bc}	7.4 ^b	40.6 ^d	22.2 ^d	3.6 ^c	0.00 ^b	66.3 ^c	1.9 ^c	14.2 ^c
FYM	33.6 ^b	53.8 ^b	7.3 ^b	59.6 ^a	32.4 ^a	8.5 ^a	3.2 ^a	103.6 ^a	1.9 ^c	23.1 ^a
Desm& FYM	35.5 ^a	55.7 ^a	7.7 ^a	58.3 ^b	28.9 ^b	7.7 ^{ab}	4.2 ^a	99.1 ^a	2.1 ^a	23.3 ^a
± SEM	0.28	0.28	0.04	0.28	0.29	0.42	0.74	1.53	0.01	0.40
<i>Forage grass (FS)</i>										
Desho grass	38.7 ^a	58.1 ^a	8.1 ^a	58.0 ^a	32.2 ^a	7.5 ^a	3.5 ^a	101.2 ^a	1.9 ^b	22.0 ^a
Napier grass	28.2 ^b	49.5 ^b	6.8 ^b	48.1 ^b	23.3 ^b	5.5 ^b	1.7 ^b	78.5 ^b	2.2 ^a	18.5 ^b
± SEM	0.20	0.20	0.03	0.20	0.20	0.30	0.52	1.03	0.01	0.29
<i>Year (Y)</i>										
2018	28.1 ^b	48.9 ^b	6.8 ^b	51.2 ^b	28.0	6.4	2.6	88.1 ^b	1.9 ^b	16.4 ^b
2019	38.8 ^a	58.7 ^a	8.1 ^a	54.9 ^a	27.5	6.6	2.6	91.6 ^a	2.0 ^a	24.1 ^a
± SEM	0.20	0.20	0.03	0.20	0.20	0.30	0.52	1.08	0.01	0.29
Overall mean	33.5	53.8	7.4	53.0	27.7	6.5	2.6	89.8	2.0	20.3
<i>P-values</i>										
F	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0020	< 0.0001	< 0.0001	< 0.0001
FS	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0157	< 0.0001	< 0.0001	< 0.0001
Y	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0929	0.5532	0.9224	0.0298	< 0.0001	< 0.0001
F*FS	0.0003	0.0051	0.0001	< 0.0001	< 0.0001	0.0009	0.2434	< 0.0001	< 0.0001	< 0.0001
F*Y	< 0.0001	< 0.0001	< 0.0001	0.0010	0.0450	0.9864	0.9999	0.6375	< 0.0001	0.0007
FS*Y	< 0.0001	< 0.0001	< 0.0001	0.2783	0.0929	0.9467	0.9755	0.5792	< 0.0001	0.1125
F*FS*Y	0.0015	0.0134	0.0196	0.9867	0.0450	1.0000	1.0000	0.9388	< 0.0001	0.4750

Means with different superscripts in a column are significantly different ($P < 0.05$, Tukey's test).

Appendix Table 5.2 Effects of fertilizer treatments on in vitro organic matter digestibility and volatile fatty acid production at Guder

Variables	GP24 ml/0.2g DM	IVOMD %	ME MJ/kg DM	VFAs and methane production (mmol L ⁻¹)						
				Acetate	Propionate	Butyrate	Valerate	TVFA	A: Pr	CH ₄
<i>Fertilizer treatment (F)</i>										
Control	30.9 ^d	53.1 ^d	7.5 ^c	44.8 ^c	24.3 ^c	4.1	1.2	74.4 ^b	1.9 ^a	16.0 ^{ab}
Desm	32.5 ^c	54.7 ^c	7.4 ^d	45.9 ^b	24.9 ^{bc}	4.3	1.3	76.3 ^b	1.8 ^b	17.1 ^a
FYM	35.6 ^b	57.7 ^b	7.9 ^b	44.9 ^{bc}	25.7 ^b	3.8	1.1	75.4 ^b	1.8 ^b	15.5 ^c
Desm& FYM	38.1 ^a	60.1 ^a	8.2 ^a	48.6 ^a	27.0 ^a	3.9	1.7	81.3 ^a	1.9 ^a	16.3 ^{ab}
± SEM	0.28	0.29	0.04	0.28	0.29	0.37	0.17	1.06	0.01	0.31
<i>Forage grass (FS)</i>										
Desho grass	39.0 ^a	59.9 ^a	8.1 ^a	45.5 ^b	26.1 ^a	3.8	1.4	76.8	1.8 ^b	15.7 ^b
Napier grass	29.5 ^b	52.9 ^b	7.4 ^b	46.5 ^a	24.9 ^b	4.3	1.2	76.9	1.9 ^a	16.7 ^a
± SEM	0.20	0.21	0.03	0.20	0.20	0.26	0.12	0.75	0.01	0.22
<i>Year (Y)</i>										
2018	31.5 ^b	53.8 ^b	7.4 ^b	44.5 ^b	25.5	3.9	1.3	75.2 ^b	1.9	13.5 ^b
2019	37.0 ^a	59.0 ^a	8.0 ^a	47.6 ^a	25.5	4.1	1.3	78.5 ^a	1.9	18.9 ^a
± SEM	0.20	0.21	0.03	0.20	0.20	0.26	0.12	0.75	0.01	0.22
Overall mean	34.3	56.4	7.7	46.0	25.5	4.0	1.3	76.8	1.9	16.2
<i>P-values</i>										
F	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.7564	0.1152	0.0003	< 0.0001	0.0078
FS	< 0.0001	< 0.0001	< 0.0001	0.0010	0.0002	0.1837	0.2622	0.9305	< 0.0001	0.0026
Y	< 0.0001	< 0.0001	< 0.0001	< 0.0001	1.0000	0.7099	0.8609	0.0042	1.0000	< 0.0001
F*FS	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.5889	0.0097	< 0.0001	< 0.0001	0.0197
F*Y	< 0.0001	< 0.0001	< 0.0001	0.1228	1.0000	0.9990	0.9997	0.9108	1.0000	0.9443
FS*Y	< 0.0001	< 0.0001	< 0.0001	0.9819	1.0000	1.0000	0.9999	0.9994	1.0000	0.9423
F*FS*Y	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.7564	0.1152	0.0003	< 0.0001	0.0078

Means with different superscripts in a column are significantly different ($P < 0.05$, Tukey's test). Control, no fertilizer treatment.

Abbreviations: A: Pr, acetate to propionate ratio; CH₄, methane; Desm, *Desmodium intortum*; DM, dry matter; FYM, farmyard manure; GP24, 24-h gas production; IVOMD, in vitro organic matter digestibility; ME, metabolizable energy; TVFA: total volatile fatty acids

Appendix Table 5.3 Relative change on chemical composition under various fertilizer treatments at Aba Gerima

Treatments	Percent increase or decrease						
	Ash	NDF	ADF	ADL	EE	CP	GE
Napier alone	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Napier+FYM	-1.58	6.47	4.43	-5.55	14.36	-5.73	3.71
Napier+Desm	0.69	3.98	-4.93	-12.99	5.95	-11.33	4.82
Napier+Desm+FYM	-1.56	6.54	8.40	2.87	17.87	-0.06	0.22
Desho alone	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Desho +FYM	0.20	-6.00	9.64	6.85	-8.16	-12.43	-4.62
Desho +Desm	4.92	-4.90	2.60	-6.15	-24.10	-4.36	-1.26
Desho +Desm+FYM	1.61	-3.92	8.23	5.96	2.80	-12.42	-0.48

Appendix Table 5.4 Relative change on chemical composition under various fertilizer treatments at Guder

Treatments	Percent increase or decrease						
	Ash	NDF	ADF	ADL	EE	CP	GE
Napier alone	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Napier+FYM	2.14	-0.01	-5.12	4.03	5.27	2.55	0.19
Napier+Desm	-0.66	-3.72	-12.45	0.47	-2.38	-5.10	-3.35
Napier+Desm+FYM	-0.37	-7.41	-6.62	3.92	7.53	1.43	-3.18
Desho alone	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Desho +FYM	-3.02	-5.55	-9.99	-5.45	25.75	4.91	-1.49
Desho +Desm	2.62	-0.44	-7.43	-8.80	6.80	-8.11	-1.02
Desho +Desm+FYM	-1.17	-2.24	-12.13	-11.14	25.75	5.18	0.25

ADF: acid detergent fiber; ADL: acid detergent lignin; CP: crude protein; Desm: *Desmodium intortum*; EE: ether extract; FYM: farmyard manure; GE: gross energy.

Appendix Table 5.5 Relative change on in vitro gas and volatile fatty acid production of forage grasses under various fertilizer treatments at Aba Gerima

Treatments	Percent increase or decrease									
	GP	IVOMD	ME	Acetate	Propionate	Butyrate	valerate	TVFA	A: Pr	CH ₄
Napier alone	0.01	0.00	0.04	0.01	-0.02	-0.13	-0.29	0.00	-0.20	-0.02
Napier+FYM	3.52	1.24	0.59	20.32	30.76	55.31	-0.29	26.42	-14.72	22.83
Napier+Desm	11.33	5.09	4.77	-21.41	-10.87	-10.33	0.00	-19.65	-10.80	-25.77
Napier+Desm+FYM	12.37	6.65	5.52	20.11	15.27	49.38	66.54	23.09	6.03	27.62
Desho alone	0.00	0.00	0.03	0.00	-0.01	0.03	-0.11	0.00	0.15	-0.01
Desho +FYM	2.86	0.99	0.41	1.10	1.75	0.15	6.44	1.47	1.01	1.09
Desho +Desm	0.11	-0.23	-1.64	-40.62	-33.22	-52.23	0.00	-48.95	-5.40	-61.29
Desho +Desm+FYM	8.58	4.67	4.52	-2.77	-2.60	-7.69	-0.34	-2.98	1.51	-3.37

Appendix Table 5.6 Relative value on in vitro gas and volatile fatty acid production of forage grasses under various fertilizer treatments at Guder

Treatments	Percent increase or decrease									
	GP	IVOMD	ME	Acetate	Propionate	Butyrate	valerate	TVFA	A: Pr	CH ₄
Napier alone	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Napier+FYM	16.98	9.25	8.42	1.43	10.12	-2.35	3.58	4.17	-7.96	-2.72
Napier+Desm	6.07	2.34	2.65	-4.34	-5.47	-13.22	-12.72	-5.29	2.64	-4.86
Napier+Desm+FYM	24.67	13.74	13.31	8.68	14.97	13.11	19.73	11.20	-7.37	6.70
Desho alone	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Desho +FYM	2.57	1.66	0.61	-1.33	1.01	-12.92	-37.61	-1.53	-1.05	-4.10
Desho +Desm	-13.78	-7.76	-7.40	8.56	8.80	3.84	43.75	9.40	1.03	8.86
Desho +Desm+FYM	6.67	4.57	3.28	6.73	5.38	-3.12	-8.70	5.57	1.17	5.86

Means with different superscripts in a column are significantly different at ($P < 0.05$, Tukey's test). Control, no fertilizer used.

Abbreviations: A: Pr, acetate to propionate ratio; CH₄, methane; Desm, *Desmodium intortum*; FYM, farmyard manure; GP, 24-h gas production; IVOMD, in vitro organic matter digestibility; ME, metabolizable energy; TVFA: total volatile fatty acids.

LIST OF APPENDIX FIGURES



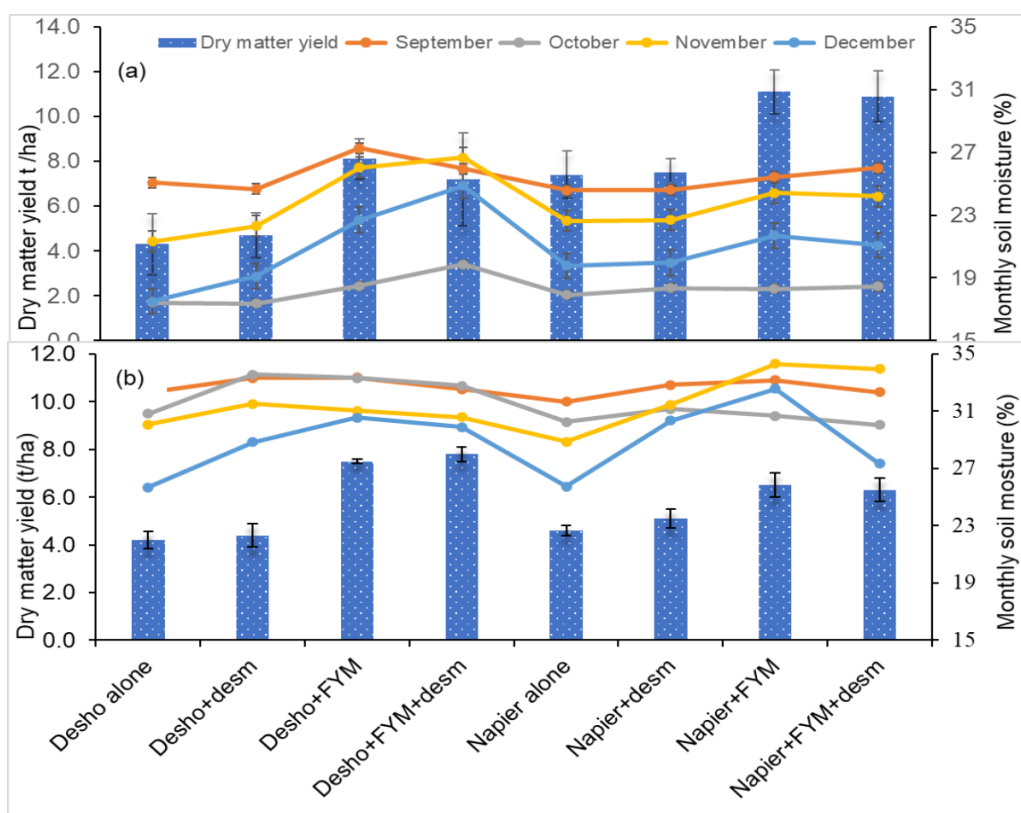
Appendix Figure 4.1 Land preparation and planting (a) and forage grasses at vegetative stage (b) Aba Gerima watershed



Appendix Figure 4.2 Forage grasses at vegetative stage (a) and data collection (b) at Guder watershed



Appendix Figure 4.3 Excavation of forage grass for root parameters (left) and sock in tape water for washing (right)



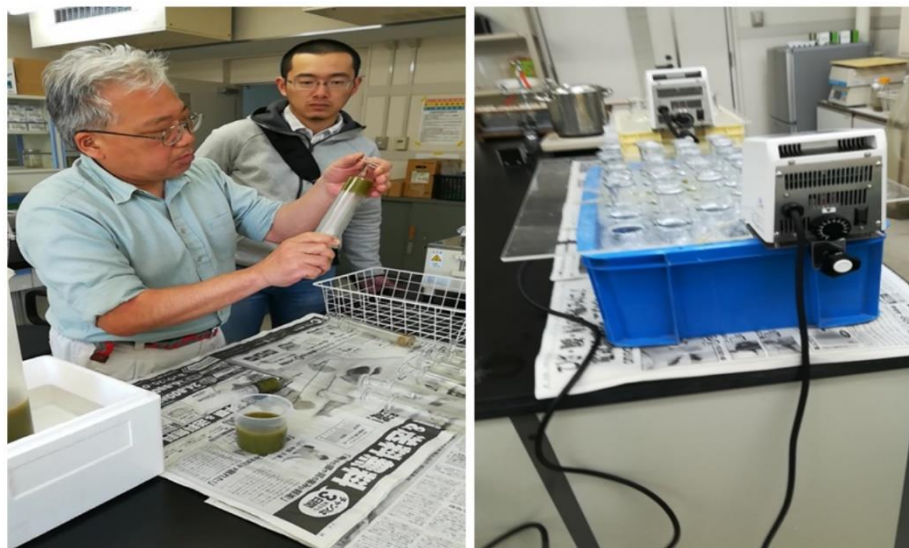
Appendix Figure 4.4 Effect of soil moisture level on dry matter yield (a) Aba Gerima and (b) Guder watershed



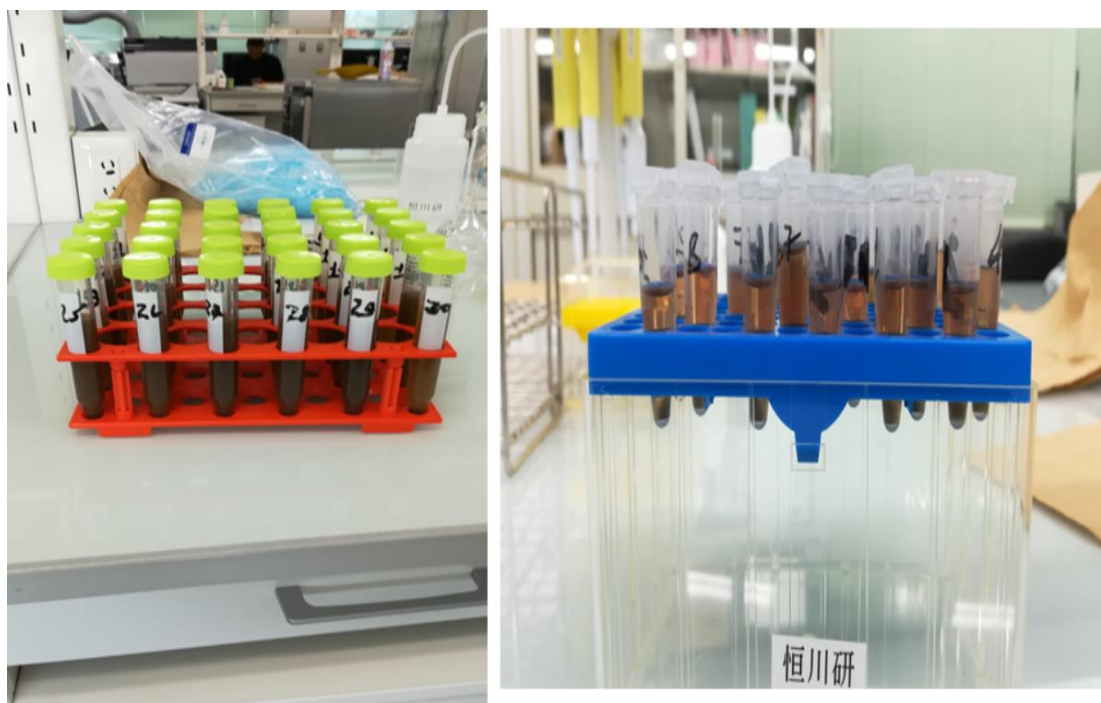
Appendix Figure 5.1 Determination of forage nitrogen and carbon level, samples injecting to CN coder machine (left) and after burning for extraction (right)



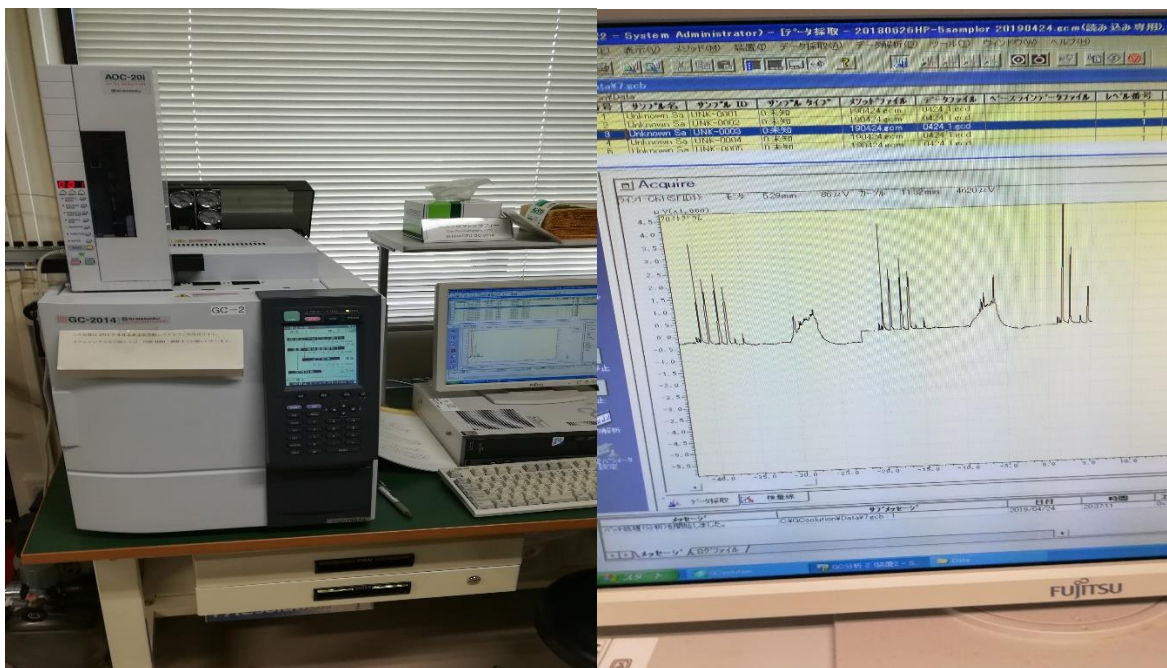
Appendix Figure 5.2 Determination of gross energy using bomb calorimeter, injecting in to bomb calorimeter (a) and data observation (b) in Shimane Science and Technology.



Appendix Figure 5.3 Rumen fluid mixed with medium is added to a 200 mg forage sample (left) and placed in an incubation chamber heated to 39 °C (right) for in vitro gas production.



Appendix Figure 5.4 Rumen fluid with culture medium after 96 h (left) and centrifugation for volatile fatty acid production (right)



BIOGRAPHY OF THE AUTHOR

Misganaw Walie Belete was born in February 1973 in Hulet Eju Enessie district of East Gojam Zone of Amhara Regional State, Ethiopia. He passed early school age, first at Tiklidingay Elementary, and then at Sedie Elementary and Junior Secondary Schools. He attended his high school education at Motta Senior Secondary School. He successfully passed the Ethiopian School leaving certificate examination and joined Alemaya University in October 1993, where he studied Animal Sciences and graduated in July 1996. He was first recruited by the Amhara Region Bureau of Agriculture as a livestock and fisheries expert in the Enebsie Sar Midir district of East Gojjam Zone Agriculture and Rural Development. Then, after he served in different districts and at zonal level, He again joined Haramaya University in October 2007 for his Master of Science degree and graduated in November, 2009 in animal production, and then returned to East Gojjam Zone Agriculture and Rural Development Office as an animal feed and nutrition expert. Later, in December 2011, he was employed by Amhara Regional Agricultural Research Institute and assigned to Sirinka Agricultural Research Center to work as an associate researcher in the animal feeds and nutrition research division. Then he transferred to Andassa Livestock Research Center and worked as a researcher in animal feeds and nutrition and as coordinator for the livestock research directorate.

He has authored and co-authored 25 scientific publications in his 18 years of research and development service (12 peer-reviewed journal articles, 11 articles in conference proceedings, and 2 working manuals). Now he is a candidate for the Degree of Doctor of Philosophy (PhD) in Animal Nutrition to the College of Agriculture and Environmental Sciences, Bahir Dar University in February, 2023.

Article publications

1. Peer Reviewed Journal Articles Emanated from this Dissertation

This PhD thesis is submitted as partial fulfilment of the requirements for the degree of Philosophy Doctor (PhD) at the Bahir Dar University (BDU), College of Agriculture and Environmental Science (CAES), Bahir Dar, Ethiopia. The thesis is based on three papers, of which two have been published and one accepted for publication.

1. Misganaw Walie, Firew Tegegne, Yeshambel Mekuriaw, Atsushi Tsunekawa, Nobuyuki Kobayashi, Toshiyoshi Ichinohe, Nigussie Haregeweyn, Asaminew Tassew, Shigdaf Mekuriaw, Tsugiyuki Masunaga, Mitsuru Tsubo, Enyew Adgo & Derege Tsegaye Meshesha. 2022. Nutritional value and in vitro volatile fatty acid production of forage grasses cultivated using farmyard manure and *Desmodium intortum* intercropping in the upper Blue Nile basin, Ethiopia. *Advances in Agriculture*, Vol. 2022, Article ID 6593230, <https://doi.org/10.1155/2022/6593230>.
2. Misganaw Walie, Firew Tegegne, Yeshambel Mekuriaw, Atsushi Tsunekawa, Nobuyuki Kobayashi, Toshiyoshi Ichinohe, Nigussie Haregeweyn, Asaminew Tassew, Shigdaf Mekuriaw, Tsugiyuki Masunaga, Toshiya Okuro, Mitsuru Tsubo, Derege Tsegaye Meshesha & Enyew Adeg. 2022. Effects of farmyard manure and *Desmodium* intercropping on forage grass growth, yield, and soil properties in different agro-ecologies of Upper Blue Nile basin, Ethiopia. *Cogent Food & Agriculture*, 8:1, 2082041, <https://doi.org/10.1080/23311932.2022.2082041>.
3. Misganaw Walie, Firew Tegegne, Yeshambel Mekuriaw, Atsushi Tsunekawa, Nobuyuki Kobayashi, Toshiyoshi Ichinohe, Nigussie Haregeweyn, Asaminew Tassew, Shigdaf Mekuriaw, Tsugiyuki Masunaga, Toshiya Okuro, Mitsuru Tsubo, Derege Tsegaye Meshesha, Enyew Adeg & Temesgen Mulualem. 2022. Biomass yield, Nutritional value, and Soil nutrient status of grazing land as influenced by farmyard manure and enrichment planting. (Accepted in *Rangeland Ecology & Management*).

1. Other journal articles

Mulualem, T., Adgo, E., Meshesha, D.T., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Ebabu, K., Kebede, B., Berihun, M.L., **Walie, M.**, Mekuriaw, S., & Masunag, T., 2021. Exploring the

variability of soil nutrient outflows as influenced by land use and management practices in contrasting agro-ecological environments. Science of the Total Environment. 786, 147450. <https://doi.org/10.1016/j.scitotenv.2021.147450>, IF-7.97.

2. Conference and poster presentations

- Misganaw Walie, Firew Tegege, Yeshambel Mekuriaw, Atsushi Tsunekawa, Nobuyuki Kobayashi, Toshiyoshi Ichinohe, Nigussie Haregeweyn, Asaminew Tassew, Shigdaf Mekuriaw, Tsugiyuki Masunaga, Toshiya Okuro, Mitsuru Tsubo, Derege Tsegaye Meshesha, Enyew Adegö & Temesgen Mulualet. 2022. Effects of application of farmyard manure and enrichment planting with improved forages on biomass yield, forage nutritional value, and soil properties of grazing land in north western, Ethiopia. A paper presented at 2022 International conference on Water, Energy and Food Security, July 4-5, 2022, Sapphire Addis Hotel, Addis Ababa, Ethiopia.
- Misganaw Walie, Firew Tegege, Yeshambel Mekuriaw, Kobayashi Nobuyuki, Toshiyoshi Ichinohe, Nigussie Haregeweyn, Asaminew Tassew, Shigdaf Mekuriaw. Evaluation of the influence of *Desmodium* and Farmyard manure on the Agronomic Performance and yield of Selected Improved grasses in the Upper Blue Nile Basin, Ethiopia. Poster presentation at the 1st mid-term Evaluation of Science and Technology Research Partnership for Sustainable Development (SATREPS) project workshop, Bahir Dar, Ethiopia, November 19 (2019).