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EFFECTS OF SPACING, VETCH INTERCROPPING, NITROGEN FERTILIZATION AND HARVESTING HEIGHT ON AGRONOMIC PERFORMANCE AND NUTRITIVE VALUE OF ELEPHANT GRASS IN THE CENTRAL HIGHLANDS OF ETHIOPIA

PhD Dissertation

By

Bizelew Gelayenew Aytegeb

Addis Ababa University
College of Veterinary Medicine and Agriculture
Department of Animal Production Studies
PhD Program in Animal Production

December, 2020
Bishoftu, Ethiopia

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

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December, 2020

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Addis Ababa University

College of Veterinary Medicine and Agriculture

Department of Animal Production Studies

As members of the examination board of the final PhD open defense, we certify that we have read and evaluated the dissertation prepared by **Mr. Bizelew Gelayenew** entitled **"Effects of Spacing, Vetch Intercropping, Nitrogen Fertilization and Harvesting Height on Agronomic Performance and Nutritive Value of Elephant Grass in the Central Highlands of Ethiopia"** and recommended that it be accepted as fulfilling of the dissertation requirement for the Degree of **Doctor of Philosophy in Animal Production.**

Gebeyehu Goshu (PhD)	________________	__________________
Chairman	Signature	Date
Gebreyohannes Berhane (PhD)	________________	__________________
Internal Examiner	Signature	Date
Solomon Mengistu (PhD)	________________	__________________
External Examiner	Signature	Date

I hereby certify that I have read the revised version of this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

Berhan Tamir (PhD, Professor)	________________	__________________
Major Advisor	Signature	Date
Getnet Assefa (PhD)	________________	__________________
Co-Advisor	Signature	Date
Fekede Feyissa (PhD)	________________	__________________
Co-Advisor	Signature	Date
Gebreyohannes Berhane (PhD)	________________	__________________
Department Chairperson	Signature	Date

DEDICATION

This dissertation is dedicated to the memory of my father (Gelayenew Aytegeb), sister (Sahile Gelayenew) and brothers (Asfaw Gelayenew, Ayenew Gelayenew, Mare Gelayenew and Malede Getaneh) who passed away untimely without seeing my success.

STATEMENT OF AUTHOR

First, I declare that this dissertation is my bonafide work and that all sources of materials used for this dissertation have been duly acknowledged. This dissertation has been submitted for fulfillment of the requirement for a PhD degree at Addis Ababa University, College of Veterinary Medicine and Agriculture and it is deposited at the University/College library to be made available to borrowers under the rules of the library. I solemnly declare that this dissertation is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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Name: Bizelew Gelayenew Signature: ______________

Place: College of Veterinary Medicine and Agriculture, Bishoftu, Ethiopia

Date of Submission: __________________

BIOGRAPHICAL SKETCH

The author was born in May 1978 in Lay Gaint district (Nefas Mewcha) South Gondar Zone of Amhara Regional State. He attended his elementary and junior high school at Kulit Amba and Gob Gob in South Gonder Zone, respectively and senior secondary school at Yekatit 12 Comprehensive Secondary School in Addis Ababa. Having completed his Secondary School with success in Ethiopian School Living Certificate Examination, he enrolled at the then Alemaya (now, Haramaya) University in September 1999 where he studied Animal Sciences and graduated with BSc. degree in July 2004. Thereafter, he was first employed in Bale Agarfa Agricultural Technical Vocational Education and Training (ATVET) College as a junior instructor in the Department of Animal Sciences. After serving for two and half years the author was transferred to Gambella ATVET College in the Department of Animal Sciences as Instructor I and served for further two and half years. He then joined Hawassa Univerisity in September 2009 for his Master of Science degree study in Animal production and graduated in July 2012 and then he returned to Gambella ATVET College.

After he returned to Gambella ATVET College and served for six months as a lecturer and Department Head of Animal Sciences, he joined Mettu University, Gambella Agricultural and Natural Resource Faculty, Department of Animal Science in November 2012 and served as a full time lecturer as well as Department Head until he joined Addis Ababa University, College of Veterinary Medicine and Agriculture in the Department of Animal Production studies in October 2015 for his PhD study in Animal Production. After he joined the college for PhD study, he returned to Gambella University in 2015 when the Faculty became a full-fledged University standing independent from Mettu University.

At the University the author had actively participated in budget planning, grade approval committee; designing of livestock farm projects, farm practical coordinator and module writing in principles of animal nutrition and introduction to animal sciences. He developed his academic capability by attending short term trainings in statistics at the Ethiopian Institute of Agricultural Research (EIAR) and received certificates upon successful completion of course. Bizelew is married and a father of a daughter and two sons.

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Finally, I would like to take this opportunity to express my deepest appreciation to all individuals who have directly or indirectly supported and encouraged me during my study period.

LIST OF ABBREVIATIONS

ADF - Acid detergent fiber
ADL - Acid detergent lignin
ATVET - Agricultural Technical Vocational Education and Traing
ANOVA - Analysis of variance
AOAC - Association for Official Analytical Chemists
CEC - Cation Exchange Capacity
CP - Crude protein
CPY - Crude protein yield
CSA - Central Statistical Agency
CV - Coefficient of variation
CVMA - College of Veterinary Medicine and Agriculture
DAP - Diammonium phosphate
DM - Dry matter
DMD - Dry matter digestibility
DMY - Dry matter yield
EARO - Ethiopian Agricultural Research Organization
ED - Effective degradability
EIAR - Ethiopian Institute of Agricultural Research
GDP - Gross Domestic Product
GLM - General Linear Model
HARC - Holetta Agricultural Research Center
HH - Harvesting height
ILRI - International Livestock Research Institute
IPMS - Improving Productivity and Market Success
IVDMD - *In vitro* dry matter digestibility

LIST OF ABBREVIATIONS (Continued)

IVOMD	-	*In vitro* organic matter digestibility
LSD	-	Least significant difference
LSR	-	Leaf to stem ratio
masl	-	Meters abave sea level
Meq	-	Milli equivalent
NDF	-	Neutral detergent fiber
NIRS	-	Near infrared reflectance spectroscopy
OC	-	Organic carbon
OM	-	Organic matter
NTPP	-	Number of tillers per plant
PD	-	Potential degradability
Ppm	-	Parts per million
RCBD	-	Randomized Complete Block Design
RH	-	Relative humidity
RF	-	Rainfall
SAS	-	Statistical Analysis System
SEM	-	Standard Error of Means

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EFFECTS OF SPACING, VETCH INTERCROPPING, NITROGEN FERTILIZATION AND HARVESTING HEIGHT ON AGRONOMIC PERFORMANCE AND NUTRITIVE VALUE OF ELEPHANT GRASS IN THE CENTRAL HIGHLANDS OF ETHIOPIA

Bizelew Gelayenew Aytegeb

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ABSTRACT

The role of improved forage crops with proper management practices in enhancing the quantity and quality of fibrous feeds has been widely recognized. This study was conducted to evaluate agronomic performance and quality of elephant grass due to the effects of spacing, vetch intercropping, nitrogen fertilization and harvesting height in the central highlands of Ethiopia at Holetta and Debre Zeit. The experiments were laid out in a randomized complete block design. In experiment 1- vetch intercropping and elephant grass spacing: S1 (75 x 75 cm), S2 (100 x 50 cm), S3 (125 x 25 cm) and S4 (50 x 50 cm) were evaluated. Most measured traits revealed significant ($P<0.05$) differences between the treatments, locations and years. Vetch intercropping had more 70.0 and 8.5% dry matter yield (DMY) advantage over pure stand elephant grass at Holetta and Debre Zeit, respectively. When combined over years and locations, average annual DMY was 9.47, 12.16 and 12.01 t ha^{-1} for elephant grass planted in pure stand, intercropped with V. dasycarpa and V. villosa, respectively. In the combined analysis, forage DMY produced was 12.96, 11.02, 10.55 and 10.32 t/ ha when planted at spacings of S4, S3, S2 and S1, respectively. The crude protein (CP) content, in vitro dry matter digestibility (IVDMD) and in sacco dry matter degradability (DMD) were higher in vetch intercropping treatments than pure stand elephant grass over years and locations. Generally, vetch intercropping after three weeks of elephant grass planting at inter and intra row spacing of 50 cm substantially improved annual forage productivity. In experiment 2- harvesting heights of elephant grass: HH1 (50), HH2 (100) and HH3 (150 cm) and nitrogen *fertilizer rates: N1 (0), N2 (50), N3 (100) and N4 (150 kg/ha) were studied. Elephant grass harvested at HH2 resulted in 58.8 and 42.4% yield advantage over HH1 at Holetta and Debre Zeit, respectively. In the combined analysis, fertilizer application rate of N3 had 0.6, 16.2 and 44.5% higher yield advantage when compared with N4, N2 and N1, respectively. The CP content, IVDMD and in sacco DMD were higher at HH1 and HH2 than HH3 with comparable and higher values recorded in N2, N3 and N4 than in N1 over locations. Generally, elephant grass harvested at HH2 (100 cm) with the rate of N3 (100 kg N/ha) annually in split applications better performed in DMY, CPY, CP content, IVDMD and in sacco DMD. In experiment 3- rates of nitrogen application: N1, N2, N3 and N4 and plant spacing: S1, S2, S3 and S4 were studied. The application of N3 at a plant spacing of S4 resulted in higher DMY advantages of 21.6 and 14.5% at Holetta and 60.0 and 32.2% at Debre Zeit than N1 and N2, respectively. When combined over locations, average annual DMY and CPY were 6.77, 7.84, 9.92, 10.69 t/ha and 0.51, 0.62, 0.83, 0.88 t/ha in application rates of N1, N2, N3 and N4, respectively. The DMY and CPY of elephant grass were comparable and significantly (P<0.05) higher in N3 and N4 than N1 and N2. In the combined analysis, forage DM produced in 7.08, 9.07, 8.51 and 10.57 t/ha when planted at spacings of S1, S2, S3 and S4, respectively. S4 had 24.2, 16.5 and 49.3% higher DMY advantage when compared with S3, S2 and S1, respectively. The CP content and IVDMD were higher in N3 and N4 than in N1 and N2 at Debre Zeit and over locations but the CPcontents were comparable and grater in N2, N3 and N4 than N1 at Holetta. Overall, in split applications of N3 (100 kg N/ha) annually at a spacing of S4 (50 cm) substantially improved the productivity of elephant grass. In view of its high potential and wider use as fodder, the different agronomic practices of this study should be evaluated under irrigation schemes and wider environments. Future research needs also to focus on management practice to minimize environmental stresses like frost and drought, and designing appropriate conservation practices is very essential.*

***Keywords**: Elephant grass; vetch species; vetch intercropping, agronomic performance; crude protein yield; nutritional quality*

1. INTRODUCTION

Ethiopia has large livestock population in Africa. It is estimated to be 60.39 million cattle, 31.30 million sheep, 32.74 million goats, 56.06 million poultry, 2.01 million horses, 0.46 million mules, 8.85 million donkeys and 1.42 million camels’ population (CSA, 2018). The subsector contributed approximately 16-25% of the total Gross Domestic Product and 40-44% of the Agricultural Gross Domestic Product in Ethiopia (Stapleton, 2016).

Currently, livestock plays a central role in the Ethiopian agriculture, however, the productivity per animal is very low and the contribution to the overall economy is much lower than expected. Among many factors constraining the development of livestock, feed shortage has remained to be the main restraining factor hindering the livestock productivity subsector in the country (Yayneshet, 2010; Alemayhu and Getnet, 2012; Getnet *et al*., 2016). The main feed resources for livestock in Ethiopia are natural pasture and crop residues, making more than 90% of the livestock feed, but they are low in quantity and quality for sustainable animal production (Alemayehu, 2004). Although indigenous pastures contributed much to livestock feed supply, current trends indicate that they are seriously overstocked and the existing grazing lands are shrinking from time to time due rapid human population growth and encroachment of crop lands due to the need to nourish the increasing human population. Furthermore, feed supply from natural pasture fluctuates according to the seasonal rainfall dynamics (Yayneshet, 2010). In developing countries, respond to the ever increasing demand for animal products alternative strategies which improve high protein feeds supply for livestock is a priority area in the development of feed resources (Getnet, 2007).

Improved forage crops can help not only mitigate livestock feed shortages but also reduce pressure on natural pastures (Nigussie and Alemayehu, 2013). The production of sufficient quantity of good quality forages for supplementation of native pastures, roughages and crop residues is the widely advocated strategy to overcome the feed scarcity (Alemayehu *et al*., 2016). They are surely a cost effective feed instead of commercial concentrates. Concentrates replacement with improved forages from 30 to 70% has been reported to reduce up to 30% of production cost in the dairy cattle diet (Sanh *et al*., 2002).

In Ethiopia, among the introduced improved forage crops, elephant grass could play a main role in providing a substantial quantity of quality forage, both for the smallholder farmers and intensive livestock production systems under proper practices of management (Tessema, 2005; Tessema *et al*., 2010). Elephant grass is a species of deep-rooted bunch forming perennial tropical grass (Harris *et al*., 2010; Kandel *et al*., 2016**).** The grass can be propagated by using root splits or stem cuttings (Tessema, 2008) and frequently differ across agro ecological zones (Getnet and Gezahagn, 2012). When it is grown at an altitude of 2000 meters above sea level, growth and regeneration after mowing is slow (Francis, 2004) and it could be died due to frost or minimum temperature stress (Francis, 2004; Fekede *et al*., 2005), but the portions of underground continue alive unless the soil is frozen and growth resumes rapidly when situations become favorable (Fekede *et al*., 2005).

Vetches are widely grown for both livestock and soil fertility improvement (Chowhurry, *et al*., 2001) and they are well known groups of legumes with high crude protein content (Getnet and Ledin, 2001; Alzaueta *et al*, 2001). Moreover, they increase soil nitrogen through the process of nitrogen fixation in the existence of rhizobium bacteria; the fixed N ranging from 32 to 115 kg ha^{-1} (Iannetta *et al*., 2016).

In interplanting /mixtures, the subsequent crops grown require minimized fertilizer utilization, a reduction between 23 and 31 kg N ha^{-1} (Preissel *et al*., 2015). The major limiting factor of forage grasses are low crude protein content. They are usually incorporated with legumes to produce high forage quantity with more quality nutrition for livestock feeding (Mwangi *et al*., 2004; Koc *et al*., 2013). Intercropping of legumes with grasses reduce inputs through lower herbicide, pesticide and fertilizer application requirements, and it provides to a greater uptake of nutrients and water, increased land use efficiency, improved soil conservation, suppression of weeds, increasing the capture and use of light, greater productivity and profitability than pure stand cropping systems (Coll *et al*., 2012; Akman *et al*., 2013). Higher yields related with intercropping occur when the component crops are complementary to each other, resulting in a more effective use of environmental resources viz., nutrients, water and light compared to when grown pure stand (Vandermeer, 1989). Generally, the planting of high quality forage crop species with ability of a high yielding, adaptable to environmental stresses is one of the possible options to improve livestock production under situations of smallholder farmers (Tessema, 1999). But, forage crop species performances vary across locations and years due to the variations in soil fertility, temperature, and amount and distribution of rainfall.

Two main technology constituents like plant spacing and sufficient nitrogen fertilization rates are appropriate for grasses, which play a key role in growing fast and tillering profusely grasses development, such as elephant grass (Bilal *et al*., 2002). Spacing of plants substantially affects total DM yield of elephant grass (Wijitphan *et al*., 2009). Similarly, inter and intra row spacing of Bana grass (*P. purpureum x P. typhoides*) influenced the CP, NDF, ADF, ADL, Ca, P and IVDMD contents (Berihun, 2005). In most arable soils nitrogen fertilizer is commonly deficient (Havlin *et al.*, 1999) and plants grown on soils deficient in nitrogen fertilizer indicate yellowish color, retarded growth and decreased yield (Pandey and Sinha, 2006). Nitrogen develops stronger cells for photosynthesis (Bob, 2011) and benefits to grasses by escalating of forage dry matter yield and its quality in terms of crude protein content, feed intake and digestibility (Aderinola, 2007).

For most treatments of harvesting height and interval can have a considerable influence on both forage yield and quality triats (Okwori and Magani, 2010). Similarly, many research reports revealed that plant height at harvesting (Tessema *et al*., 2002b, 2003; Lounglawan *et al*., 2014), stage of growth (Tessema *et al*., 2002a; Tessema and Baars, 2003) are the major factors affecting the chemical composition and digestibility of elephant grass. The nutritional quality of plant decreases due to an increase in indigestible fiber (more stem and less leaf fractions) and a decrease in nutrient content when the plant matures. The lower the fiber values, the better the nutritional quality and digestibility of the feed, because fibrous feeds are a mechanical barrier to the attack of microorganisms on substrates in the rumen (Oliveira *et al.*, 2017). Mahala *et al*. (2009) and Keba *et al*. (2013) suggested that CP content often declines with increasing plant structural constituents (NDF, ADF and lignin) and increasing age of maturity (harvesting stage). Grasses mature faster than legumes, and the drop in nutritional quality with the delay in harvesting stage (age) is faster in grasses than in legumes (Fekede *et al*., 2014).

The livestock demands high quantity and quality of feeds for growth, reproduction, production and maintenance purposes, applying available means or technologies of acquiring adequate supply of medium to high quality feeds is essential throughout the year. However, farmers do not have adequate information on optimum management practices of elephant grass (Mutegi *et al*., 2008). Hence, to fill the information gap stated above the present study was proposed to evaluate the herbage yield and nutrient contents of two important forage species, namely, elephant grass and vetch legumes under varied plant spacing, intercropping, nitrogen fertilization and harvesting height. Therefore, the present study was undertaken with the following general and specific objectives.

General objective:

To investigate effects of different management practices on agronomic performance, forage yield and nutritive values of elephant grass in the central highlands of Ethiopia.

Specific objectives:

- To evaluate the effects of vetch intercropping and plant spacing on agronomic performance and nutritional quality of elephant grass at Holetta (higher highland) and Debre Zeit (medium highland).

- To evaluate the effects of harvesting height and nitrogen fertilization on agronomic performance and nutritional quality of elephant grass at Holetta and Debre Zeit.

- To evaluate the combined effects of nitrogen fertilization and plant spacing on agronomic performance and nutritional quality of elephant grass at Holetta and Debre Zeit.

2. LITERATURE REVIEW

2.1. Improved Forage and Pasture Crops in Ethiopia

Improved forage and pasture crops have various benefits. In the perspective of ruminant livestock production, the main advantage is to produce higher yield of better quality feed. Furthermore, improved forage and pasture crops have longer length of productive season, which provides an opportunity for dairy and fattening production to develop and use forage and pasture crops on a large scale (Alemayehu, 2006). They have been grown and used in state farms, government ranches, farmers' demonstration plots and dairy and fattening areas (Alemayehu, 1985, 2004). Forage crops are commonly grown for feeding dairy cattle like oats and vetch mixtures, elephant grass mixed with siratro and desmodium, Rhodes and lucerne mixtures, phalaris and trifolium mixtures, fodder beet, hedgerows of sesbania, leucaena and tree-lucerne. Improved forage grass and pasture species, and legumes yields ranged from 6–8 and 3–5 DM ton/ha, respectively, and for tree legumes 10–12 DM ton/ ha (Alemayehu *et al*., 2017).

Commonly, agronomic evaluation of forage crops focuses on biological attributes like ease of establishment, biomass production and resistance to diseases and pests. But in most cases, quality data base for promising materials has not been adequately generated under diverse growing conditions. Improved forage cultivation is practiced for various purposes such as source of animal feed, soil conservation, crop rotation, wind break, fence and for fuel. In Ethiopia, amongst the purpose of forage production, animal feeding, and soil and water conservation are accounted the largest share (Gebreegziabher and Tsegay, 2016; Workye *et al.,* 2018). In areas with problems of soil fertility, forage crops that can suitably be planted on soil bands, soil conservation structures and as hedge and alley crops can be considered. A summary of suggested forage species for various agro-ecologies and their production strategies have been reviewed by Adugna *et al.* (2012). In this regard, forage crops such as elephant grass, vetch, alfalfa, cow pea, lablab and others were observed to be suitable under intensified production systems according to aforementioned authors.

Many studies indicated the potential role of improved forage crops in improving animal performance (Diriba, 2014). They can generally be utilized as green feed or conserved in the form of hay or silage for later use during the lean periods. Fodders with thicker stems like elephant grass and others can more suitably be utilized as green feed using cut and carry system. As previously stated, the leguminous species are rich in crude protein and minerals and can thus be used as supplements to poor quality roughages (Cook *et al*., 2005; Diriba, 2014). The use of improved forage legumes to incorporate into existing farming systems is a valuable economic alternative to purchased protein or energy rich concentrates as a practical on-farm solution for smallholder dairy production. Similarly, in a study which compared oats-vetch mixture with native pasture hay using lactating crossbred cows, oats-vetch mixture was reported to support high milk yield (5.7 kg cow^{-1} day^{-1}) than native hay (5.0 kg cow^{-1} day^{-1}) and this difference was attributed to improved protein and energy intakes on the oats-vetch diet (EARO, 2000).

The major barriers of improved forages production in different parts of the country are land tenure, lack of seed and planting materials, ecological deterioration, drought, weed and bush encroachment, overgrazing and border conflict. Furthermore, improved forage production and utilization are restricted in the smallholder systems owing to scarcity of land, lack of effective extension system, insufficient technical and material inputs, lack of specialization in livestock production, limited market orientation, and inadequate knowledge and awareness of the farmers in the country (Zewdie *et al.*, 2011; Adugna *et al.*, 2012). The potential role of adoption for improved forages might be higher under market oriented livestock production system, for instance dairying with crossbreds or improved breeds, and fattening of large and small ruminants (Gebremedihin *et al.*, 2003). With the support of externally funded projects, distinct efforts have been made by different organizations to promote improved fodder crops in the farming communities of the country. For instance, Improving Productivity and Market Success of Smallholders (IPMS) project showed only 0.15% of rural livestock keepers reported on-farm production of some fodder crops (Tefera *et al*., 2010). In spite of the promotion of improved forage production strategies in Ethiopia since in the 1940s, the contribution of improved forage as feed of livestock is minimal (0.32%) in the country (CSA, 2018).

2.2. Characteristics of Elephant Grass

Elephant grass (*Pennisetum purpureum*) is one of the most important perennial forage grass species and it has many usages in different parts of the globe which include grazing, constituent of fish ponds, green manure, fire breaks, mulch, wind break and soil erosion control (Farrell *et al*., 2002). It has been also identified as an important tool in the integrated management of stem borers of maize and sorghum crops because of its importance as a trap crop for these pests (Midega *et al*., 2010). Elephant grass is a very multipurpose species that can be grown under a wide range of systems and conditions: larger scale or smallholder agriculture, wet or dry conditions. This grass is propagated vegetatively because seeds have low genetic stability and viability (Humphreys, 1994). Elephant grass is planted or established in well-prepared land from root splits, canes with 3 nodes or from whole canes. It is planted 15-20 cm deep with splits upright, three node canes planted at an angle of 30-45^o while whole canes are buried in the furrow 60-90 cm apart. It grows in sub-tropical and tropical regions with a wide range of annual rainfall from 750 to 2,500 mm and ranging altitudes from sea level to above 2100 m, but minimum tempreture stress or frost appears to restrict its cultivation over this altitude at the beginning of the dry season (Skerman and Riveros, 1990). Hence, it has become by far the most important species due to its wide ecological range of adaptation, ease of propagation and management, and high herbage yield (ILRI, 2010, 2013).

Elephant grass forage is a valuable and very popular throughout the tropics, particularly in cut and carry systems (FAO, 2015). It produces greater dry matter (DM) yi elds than other grasses in the tropics (Boonman, 1997) as well it possesses high nutritive value for dairyanimals especially when supplemented with feeds of high quality such as legumes (Nyambati *et al*., 2003). Lukuyu *et al*. (2012) has recommended that elephant grass weeding after each harvest to retain high productivity. Therefore, elephant grass is the choice forage crops worldwide (Hanna *et al*., 2004) due to its desirable characters such as drought tolerance and a wide-ranging of soil conditions and high water use and photosynthetic efficiency (Anderson *et al*., 2008). Moreover, it tolerates repeated defoliation under good weather conditions and it can be harvested within the range of 6-8 weeks giving up to 8 harvests annually, depending on fertilizer rate, amount and distribution of rainfall. The diverse topography together with environmental heterogeneity offers faverable environments for pasture species, herbaceous legumes and browse trees/shrubs (Muluye, 2019).

2.3. Characteristics of Vetches

In the central highlands of Ethiopia, among numerous annual forage legumes, adaptation of vetches is better and encouraging than the others. They are well adapted to altitudes ranging from 1800 to 2500 meter above sea levels with annual rainfall more than 700 mm. According to Getnet (1999), vetches are adapted and widely used in the cool tropical highlands. Moreover, they grow well on the black soils and the reddish brown clay soils in areas of the highland. Once vetch plants reach seed setting phase further seeding in the next season is not required as the seed can stay at least two years in the soil. Legumes in general and vetches in particular are excellent sources of nitrogen for livestock feed and the significance of forage legumes in livestock and crop production is well recognized.

Vetches are valuable crops as they enriched soil organic matter and nitrogen through symbiotic fixation (Haffani *et al*., 2014). They can form a symbiotic relationship with bacteria where fixation of atmospheric di-nitrogen (N2) occurs (*Hu et al*., 2012). Moreover, they contribute to soil and water conservation in a number of ways which comprising of soil cover during and after cropping seasons. Crop residues could be used for mulching material laid as the soil cover (Mupangwa and Thierfelder, 2014) or the live crops (Mhlanga *et al*., 2015). High soil covers protected the sun from directly heating the soil surface which reduces water evaporation (Farzi *et al*., 2017). Herbaceous forage legumes are multipurpose plants and generally increase resource and land use efficiency in livestock production systems by increasing forage yield and quality, particularly during the dry season; improving weed suppression, pest and disease reduction as a result of increased ground cover and ecosystem diversification; add nitrogen to the soil through symbiotic nitrogen fixation and improving nutrient cycling. Consequently, production costs are reduced and profitability is increased owing to the reduced requirements of external inputs, for instance fertilizers and pesticides, and there are benefits from less environmental contamination (Peters *et al*., 2001). They have been identified as potential protein supplements for ruminants since they comprise high crude protein (150-300 g/kg DM) content required for the growth of ruminal microbes (Norton and Poppi, 1995). They are rich nitrogen sources for feeding of livestock with cheaper prices than concentrates particularly in developing countries (Seyoum, 1995). They have greater crude protein content than many other herbaceous legumes in the tropics (Getnet and Ledin (2001). For example, vetch species has high CP content (19.9%), *in vitro* organic matter digestibility (IVOMD) (68.7%) and DM yield (4–6 t/ha) (Getnet, 1999). Moreover, as stated by Seyoum (1995) herbaceous legumes had the CP content of 12-26%, neutral detergent fiber (NDF) of 37-54%, lignin content of 7-11% and *in vitro* organic matter digestibility (IVOMD) of 53-74%. Hence, introduction of improved forage legumes for instance vetch in the farming system is a vital factor to reduce feed scarcity.

In assessing the nutritive values of forage legumes, CP content should not be used as the only parameter to be considered. The crude protein yield (CPY) which describes the overall and actual quality of forage productivity should be also used. The CPY is determined as the product of CP content and herbage DM yield (Starks *et al*., 2006).

Creeping and intermediate maturing habits of vetch species growth had comparatively enhanced ash, CP contents and CPY in tone per hectare than early ripening or maturing and erect growth habit species. Species of vetch have different characterstics in terms of growth habit, days to maturity, morphological fractions and climate adaptation. In general, growth habit of vetch species can be broadly categorized as creeping or climbing and erect types. For example, *Vicia dasycarpa and Vicia villosa* have creeping or climbing growth habit, while *Vicia narbonensis* and *Vicia sativa* have erect growth habit. These varations in genetic characterstics are the basis for difference in nutritive values and also determine the production, utilization and the various management practices (Gezahagn *et al*., 2014).

2.4. Production of Grass – Legume Mixed Forage Crops

Legumes supply nitrogen to grass-legume mixtures; in the mixtures greater yields have commonly been attained in comparison with pure stand grasses. Numerous authors have revealed better total dry matter production in grass-legume mixtures than pure stand grasses or cereals. In Northern Europe and Canada greater yield in the legume-grass mixtures than pure stand treatments in a study that was conducted by Sturludottir *et al*. (2013). Aforementioned authors also reported that on average, the grass-legume mixtures had 9, 15 and 7% higher DM production than the most productive pure stand in the first, second and third year, respectively in a study they conducted. Similarly, Gulwa *et al*. (2017) reported that higher total dry matter production in grass-legume mixtures in comparison to pure stand grasses in a study that was done in the Eastern Cape Province, South Africa. More production of grass - legume mixtures can be attributed to the higher growth rate, reduction of weeds, decreasing pests and diseases and more effective use of environmental resources like nutrients, water, space and light due to the differences in resource consumption (“complementary effects”) between the constituents of the mixtures (Zhang and Li, 2003; Mahapatra, 2011; Eskandari, 2012).

According to Eskandari *et al*. (2009a) legumes are sources of a good crude protein and can be used to compensate grass or cereal protein scarcity. Numerous authors have showed that greater crude protein content in grass-legume mixtures than pure stand grasses (Eskandari *et al*., 2009b; Ojo *et al*., 2013). Hence, legumes are commonly intercropped with grasses due to their competence to enhance the herbage yield and to produce with more balanced forage nutrition for feeding and improving livestock production and productively (Albayrak *et al*., 2011; Koc *et al*., 2013). Herbaceous legumes can give high yield when intercropped with elephant grass; those are compatible and give high yields include: giant vetch (*Vicia dasycarpa*), silver leaf desmodium (*Desmodium uncinatum*), green leaf desmodium (D. *intortum*), stylo (*Stylosanthes guianensis*), glycine (*Neonotonia wightii*), centro (*Centrosema pubescens*) and butterfly pea (*Clitoria ternatea*) (Kusewa *et al*., 1980; Orodho, 2006). The paramount use of cattle is to provide draught power in the Ethiopian highlands. Improved forage grasses provide all the needs for these animals. However, protein supply is the limiting factor for dairy cattle. Thus, milk yields are expected to increase by supplementing the legume to a grass based diets (Tilahun *et al*., 2005). Furthermore, a current meta-analysis has demonstrated that legumes in the forage enhance dry matter intake and milk production as compared with pure stand grasses (Johansen *et al*., 2018).

2.4.1. Factors affecting production of grass-legume mixtures by intercropping

Intercropping is a multiple cropping system, in which two or more crop species are planted simultaneously in the same piece of land during a growing season (Ofori and Stern, 1987). It does not mean that in the intercropping, plants can be planted at a time together, but it is the purpose that two or more crops are planted and grown together in the same plot, during their growing season or at least in a time frame. Plants are not the same in terms of planting time and a plant is planted after the first plant established (Mazaheri *et al*., 2006). Strategies of intercropping are planting a shallow-rooted crop and a deep-rooted crop, or planting a short crop and a tall crop in the mixtures that requires shade partly. Likewise, the mixture can contain annual plants with annual plants and perennial plants with perennial plants (Ghanbari and Lee, 2003; Eskandari *et al*., 2009a). Generally, herbaceous legumes are more compatible with erect bunch forming grasses compared with stoloniferous grasses (Hare *et al*., 2004).

Tropical grass-legume mixtures by intercropping have been successful where the management allows the legume component to compete favorably with grasses (Hernandez *et al*., 1995). However, there are some factors that affect the growth of plant species used in the intercropping, namely, cultivar selection, mixture ratios, spacing and competition between the constituents of mixtures (Dhima *et al*., 2007; Akman *et al*., 2013), and in addition cultural practices such as seedbed preparation, planting of seeds and subsequent management practices of crops (Lithourgidis *et al*., 2011). Between the mixture species, there can be aboveground competition for space and light, and belowground competition for nutrients and water (Mariotte *et al*., 2012). Thus, above and belowground competition conditions have important impacts on the production of grass-legume mixtures and these factors should be taken into consideration in the intercropping system.

The effects of different mixture ratios in the intercropping system have been assessed in many studies. Pinar (2007) and Ozel (2010) reported that increasing the ratio of those vetches whose forage quality was higher in the mixtures increased both forage yield and nutrient content. Other researchers revealed contrary findings that increasing rate of cereal/grass whose dry matter content was higher, resulted in a higher forage yield, but lower forage quality (Dhima *et al*., 2007; Gunduz, 2010; Bedir, 2010). Similarly, an increased ratio of the grass in mixtures with vetch considerably decreases the stand lodging and has a positive effect on the forage yield, but the nutrient is inferior in quality (Karagic *et al*., 2012), because a high grass proportion in the botanical composition of grass- legume mixtures causes low protein content.

2.4.2. Advantages of intercropping

Intercropping is common, especially in countries with high extents of subsistence agriculture and low extents of agricultural mechanization. Intercropping is frequently undertaken by farmers with low-input (high labour), low-yield farming on small areas of land (Ngwira *et al*., 2012). Under these situations, intercropping can support increased cumulative yields per unit input, insure against crop failure and market fluctuations, meet food preference and cultural demands, protect and improve soil quality, and increase income (Rusinamhodzi *et al*., 2012). Advantages of intercropping in the crop production in comparison with pure stand cropping are due to the interaction between components of crop mixtures and the variation in competition for environmental resources utilizaion (Mahapatra, 2011). The major advantages of intercropping are discussed in the following sections.

2.4.2.1. Efficient use of resources

One of the main reasons for the use of intercropping around the world is produced more yields than a pure stand cropping in the same amount of land (Caballero and Goicoechea, 1995). Biomass production of diverse species systems was, on average, 1.7 times greater than in pure stand cropping system in 79% of biodiversity experiments (Cardinale *et al*., 2007). If the intercropping components are complementary in the use of environmental resources, therefore it is more effective than a pure stand cropping (Eskandari *et al*., 2009b; Eskandari and Kazemi, 2011). Grass - legume mixtures by intercropping permit reduced inputs through lower fertilizer and pesticide requirements, and it gives to a more uptake of moisture and nutrients, enhanced soil conservation, increased land use efficiency, improving the capture and use of light, weeds supression, better productivity and profitability compared to pure stand cropping system (Coll *et al*., 2012; Akman *et al*., 2013). Furthermore, intercropping can decrease the nitrate leaching from the soil profile since it utilizes the soil nutrients more efficiently than pure stand cropping systems (Zhang and Li, 2003).

2.4.2.2. Productivity

Forage productivity is affected by differences in environmental and management factors. The soil fertility, moisture (water), ambient temperature, and planting and harvesting management are some of the major factors. Intercropping in the mixtures can substantially increase total forage productivity as compared to pure stand cropping systems owing to better utilization of water, nutrients and solar energy (Qin *et al*., 2013; Matusso *et al*., 2014). Meta-analysis carried out by Cardinale *et al*. (2007) showed that mixtures are more productive than the average pure stand cropping in 79% of the 44 experiments. Legumes are especially good source of protein and integrating them in to the cropping system could be of paramount significance for the nutritional quality of the forage (Nadeem *et al*., 2010). The main reasons for higher forage productivity in grass-legume mixtures by intercropping could be due to the symbiotic fixed nitrogen utilization (Whitehead, 1995), more improved light interception (Hay and Walker, 1989) and allelopathic. For instance, oats-legume mixtures considerably increase the dry matter and nutritive value, suggesting a better alternative to utilize per unit area of land for a maximum productivity of forage dry matter yield, enhancing the quality issue, and with the potential to reduce weed infestation (Dangi *et al*., 2018).

2.4.2.3. Effects on soil fertility

Cultivation of forage grass-legume mixtures by intercropping provides not only high quality feed for livestock but also they are complementary to the crop production through improving soil fertility. The soil fertility emanating from biological nitrogen fixation by the legumes comprise the improvement of soil nutrients, soil organic matter content, soil pH, soil structure, soil porosity, biological diversity and pest cycle (Malik, 2010; Mohammadi *et al*., 2012). Rhizobium bacteria are able to have a symbiotic relationship with plants of leguminosae family and can fix atmospheric nitrogen (N_2) into available form of nitrogen for plants uptake. They have the potential to be nitrogen self-sufficient and increase nitrogen availability in the soil for associated or subsequent crops, forage grasses and soil biota by fixing atmospheric nitrogen (Chultze-Kraft *et al*., 2018). Therefore, integration of forage legume in to grass mixtures improves forage quantity, quality and soil fertility trough the addition of nitrogen. There are several reports demonstrating that increasing the availability of nitrogen in non-legume plants due to the intercropping of grasses with plants of leguminosae family (Eskandari *et al*., 2009a; White *et al*., 2013; Li *et al*., 2014).

2.4.2.4. Contributions for pest, disease and weed control

One of the main benefits of intercropping is its ability to reduce pest and disease damage. Even though intercropping does not constantly reduce pest or pathogen, but most findings have showed that reduction of pests and diseases populations (Fujita *et al*., 1992; Anil *et al*., 1998; Ratnadass *et al*., 2012). In a review reported by Francis (1989) in intercropping, 53% of the experiments reduced the pest and 18% increased the pest than the pure stand cropping systems. In intercropping systems, increased pests can be owing to a number of reasons, for instance the second crop is a host for pests, or increasing the shade in canopy which provides ideal conditions for pests and pathogens activity. More species diversity in agricultural ecosystems can restrict the spread of plant pathogenic. This system increases biodiversity like the natural ecosystems. Legumes have quicker rates of growth than several weeds; hence they can have a competitive benefit over weeds (Mhlanga *et al*., 2015). Weeds interfere with forage and pasture crops triggering serious impacts through competition for nutrients, water, space and light. Intercropping configurations are more effective than pure stand cropping in weed suppressions, but their effectiveness varies considerably (Girjesh and Patil, 1991). It is an agricultural practice which can be used for reducing the dependency on chemical herbicides in weed control (Banik *et al*., 2006; Corre-Hellou *et al*., 2011). The positive effect of mixtures on weed suppression can generally be attributed to more efficient resource use in the mixtures than in monocropping systems (Suter *et al*., 2017).

2.4.2.5. Sustainable productivity

The increasing concerns of environmental impacts and reduction of inputs need the present cropping systems to transform for improved efficiency and sustainability (Vander meer *et al*., 1998). Any production systems sustainability can be influenced by the economic returns and the feasibility of various cropping practices. Numerous researches reported that intercropping practices can confirm higher yield as well as productivity and profitability in crops per unit land (Yildirim and Turan 2013). When crops can be grown together in the same field, fail to produce a product, might be compensated by other crop, and thus reduces the hazard. Hazard of agronomy failure in intercropping is lower than pure stand cropping systems. It can be suitable growth condition for a species and unsuitable for the other species (Eskandari *et al*., 2009a). Similarly, the development of sustainable food production systems by intercropping is very vital predominantly in cropping systems with limited external inputs (Adesogan *et al*., 2002).

2.4.3. Major challenges of intercropping

Intercropping of grasses and legumes can be an alternative to enhance the forage production, quality, and the profitability and system sustainability in tropical regions (Resende *et al*., 2003). However, the main limitation for the introduction of legumes in the production systems is their low persistence under grazing (Barcellos *et al*., 2008). Furthermore, some factors that affect the growth of plant species used in the intercropping includes in cultivar selection, seeding ratios, mixture ratios, spacing and competition between the constituents of mixtures (Dhima *et al*., 2007; Akman *et al*., 2013), additional work in preparing, planting of seeds and management practices of crops (Lithourgidis *et al*., 2011). Between the mixture species, there may be aboveground competition for space and light, and belowground competition for nutrients and water (Mariotti *et al*., 2009; Mariotte *et al*., 2012). Thus, aboveground and belowground competition conditions have important impacts on the production of grass-legume mixtures and these factors should be considered in the intercropping system.

2.5. Planting Density and Spacing

The optimum planting density is a big challenge all the time to the farmers. Substandard plant density result in high weeds infestation, poor radiation use efficiency and low yield, whereas dense plant population on the other hand cause lodging, poor light penetration in the canopy, reduce photosynthesis production due to shading of lower leaves and drastically reduce the yield (Lemerle *et al*., 2004; Lemerle *et al*., 2006). According to Tessema, (2008) reported that non significant effect of plant density on the morphological characteristics of elephant grass was recorded during the establishment year. Agronomic studies conducted on grasses revealed that the use of relatively cost-effective and easy practices of management for instance correct or adjuste spacing of plant, consistent weeding, application of optimal fertilizer rates and appropriate harvesting height can help to increase the fodder production (Yasin *et al*., 2003). Proper spacing enables to keep the farmers appropriate plant population (plant density), avoid over and under population in a given plot of land which has negative effect on yield and quality (EARO, 2004). Plant spacing differs depending on the annual rainfall of the area; usually the higher the rainfall the closer the spacing is required. For inter-row and intra-row spacing of elephant grass production, 50 cm × 50 cm in Ethiopia and Japan (Ishii *et al*., 2005; Tessema, 2008), 100 cm × 50 cm in in Ethiopia and Ghana (Tessema, 2000; Tessema *et al*., 2003; Ansah *et al*., 2010) and 100 cm × 100 cm in Kenya (Nyambati *et al*., 2010) have been suggested. Berihun (2005) also reported that a significant effect of plant spacing on the dry matter yield of Bana grass in semiarid areas of Ethiopia. Similarly, Wijitphan *et al*. (2009) indicated a substantial influence of spacing on total forage dry matter yield (DMY) of elephant grass. In plant spacing of 50 cm x 40 cm, the

DM production was ranged from 2.6 - 10.19 t ha^{-1} from 11 harvests. Several studies revealed that elephant grass biomass yield was increased when inter and intra row spacing was decreased (Saeed *et al*., 1996; Sumran *et al*., 2009). Furthermore, the highest plant height of pure stand elephant grass was recorded at closer plant spacing (50 cm x 50 cm) compared to wider spacing (100 cm x 50 cm) (Tessema, 2000; Taye, 2004). Crude protein content, neutral detergent fiber, acid detergent fiber and dry matter digestibility of elephant grass was affected by plant spacing (Sumran *et al*., 2009). The CP, NDF, ADF, ADL, Ca, P and IVDMD contents of Bana grass were also affected by the combination of row and plant spacings of 100 cm x 50 cm, 100 cm x 75 cm, 75 cm x 50 cm and 75 cm x 75 cm (Berihun, 2005).

2.6. Response to Nitrogen Fertilization

High responses of crop growth, tiller production, tissue concentration of elements and yield have been related with application of nitrogen fertilizer (Onyeonagu, 2005). The majorities of highland soils are lacking in important nutrients and require fertilizer to sustain crop yields. Soils of Ethiopian are generally low in available nitrogen and phosphorus contents and cannot produce high crop yields without fertilizer applications (Alemayehu, 2006). Although soil nitrogen is adequate for forage productivity during the establishment year, it tends to drop during the subsequent years. The main way to supply nitrogen to forage plants is through chemical fertilizer application because around 99% of the nitrogen on earth is stored in the atmosphere and less than 1% is available in the earth's crust. The nitrogen molecules (N_2) are chemically inactive in the atmosphere and cannot be easily absorbed by plants. Hence, forage crops require extra nutrients from inorganic fertilizer or farmyard manure in order to attain maximum production (Lukuyu *et al*., 2012). It is considered the most important mineral for plants since it increases the availability of forage and the amount of protein.

The two possible mechanisms involved for superior yield of plants might be the regulatory role of nitrogen in production of amino acids and plant hormones responsible for cell division and enlargement (Siam *et al*., 2008). Silveira *et al.* (2015) studied the effect of N rates (0, 60 and 120 kg N/ha/year) on Bahia grass (*Paspalum notatum*) dry matter yield (DMY) which increased linearly with increasing N rates in all treatments. Generally, optimum rate of nitrogen fertilizer applications considerably increases the pasture yield. However, the efficiency of N application differs with plants, soils, seasons, climatic conditions and application techniques. To maximize the N use efficiency, these factors have to be taken into consideration (Sun *et al*., 2008). In the same way, cattle manure application at the rate of 2.0 t ha^{-1}gave a higher DMY of elephant grass than 1.0 t ha^{-1} and without manure and nitrogen applications (Tessema, *et al*., 2002b). However, the effect of cattle manure application was not considerable as compared to nitrogen fertilizer on DMY, which could be due to the small quantity of manure applied and the gradual releasing of nutrient which was not yet completely decomposed or decayed.

Nitrogen fertilizer application was slightly affected on the herbage digestibility of grasses and improved dry matter digestibility (DMD) during the early phase of growth but at the later stage of maturity the nitrogen-fertilized grasses DMD was inferior to the non-fertilized forage (Daniel, 1996). Excessive use of nitrogen fertilizer in several farmers for best economic return lead to extra nitrate accumulating in ground-water or forage which constitutes a risk to animal and human wellbeing. The fertilizer inputs are also expensive, therefore, to determine an appropriate rate of nitrogen fertilizer increase yield and economy of the farmers.

2.7. Harvesting Management

The agronomic performance and yield of elephant grass is greatly influenced by management practices, agro-ecology, climatic conditions and other edaphic factors (Utamy *et al*., 2011). For the majority of forages, treatments of harvesting and interval management can have a considerable effect on both yield and nutritive values (Okwori *et al*., 2010). However, research results on the harvesting management of elephant grass (*Pennisetum purpurem*) are scanty in the country. Forage management tools such as timely harvesting and grass-legume mixture can attain optimum forage productivity (Taye *et al*., 2007). Hence, harvesting height is an important parameter contributing to yield and quality of forage crops. Research findings have shown that elephant grass height is strongly correlated with both dry matter yield and nutritional quality of this grass (Snijders *et al*., 1992; Muia *et al*., 2000). Other research results have also revealed that plant height at harvest (Tessema, 2000; Tessema *et al*., 2003); growth stage (Seyoum *et al*., 1998; Tessema and Baars, 2003; Taye, 2004; Berihun, 2005) and varietal difference (Seyoum *et al*., 1998 and Tessema, 2005) are the major factors that affect dry matter yield, chemical composition and digestibility of elephant grass in Ethiopia. But, the optimum management practices for elephant grass species are unclear (Mutegi *et al*., 2008). Hence, appropriate harvesting management is crucial for high production and quality of elephant grass forage species (Jorgensen *et al*., 2010; Tessema *et al*., 2010).

2.8. Forage Quality

2.8.1. Chemical composition

Feed sample analysis is important for nutritionally characterizing forages and highlighting the supplemental nutrients needed, such that rations can be effectively formulated to optimize animal production. It is also valuable for quality assurance in feed manufacturing and for identifying the presence and concentrations of undesirable substances in feeds, which adversely affect animal health and productivity. Thus, feed analysis is indispensable for efficient resource use and profitability in livestock production. Forage yield and nutritional qualities are affected by growth stage, forage species, cultivar (Pascual *et al*., 2000; Rotili *et al*., 2001; Tremblay *et al*., 2003), soil type (Aumont and Salas, 1996), climate conditions (for instance, rainfall, temperature) (Pascual *et al*., 2000; Rotili *et al*., 2001) and growing conditions (Cox *et al*., 1994). The crude protein (CP) content of forage is one of the most important criteria for forage quality evaluation (Getnet and Ledin, 2001). In ruminant diet fiber is also a very essential aspect. The contents of neutral detergent fiber (NDF) and acid detergent fiber (ADF) are increased in forages with increasing maturity (Sarwar *et al*., 2006).

Legumes usually comprise less fiber contents than grasses (Kammes and Allen, 2012; Ergon *et al*., 2016). On the other hand, legumes have more lignin content than grasses on DM basis (Kuoppala *et al*., 2009). Grass-legume mixture containing lower fiber contents as mixtures are expected to reduce the NDF contents. The level of CP, energy and fiber in a given feed can give a clear indication on its digestibility, intake and its feeding value. Elephant grass on average contains 20% DM, 9% CP, 70% NDF, 50% ADF, 9% ash and 6% ADL in feed samples taken from 10 to 15 weeks of harvesting age (Gwayumba *et al*., 2002; Islam *et al*., 2003). The CP content below 6% disturbs animal health and reproduction (Muhammad *et al*., 2010). Furthermore, the quality of forage is very essential for human nutrition as the forage eaten by the ruminant is cycling into the human food supply as milk and meat.

2.8.2. In vitro digestibility

Feed digestibility using *in vitro* biological methods which simulates the actual digestions process is a more significant technique of feed assessment as microorganisms and enzymes are more sensitive to factors influencing the rate and extent of digestion than the chemical methods (Van Soest, 1994), The *in vitro* dry matter digestibility (IVDMD) technique is used widely to analyze feeds because of the high degree of correlation with *in vivo* DM digestibility (Tilley and Terry, 1963; AOAC, 1990). Forage digestibility is associated with intake, dietary nitrogen content and physical form of the forage. Forages with crude protein contents above 6 - 8% have greater digestibility because of the availability of required N for ruminal microbes (Styler *et al*., 1979). However, there is an inverse relation between the ADF content of forage and its dry matter digestibility (DMD) and total digestible nutrients values. Similar relation has been observed between the NDF content of forage and its dry matter intake value; viz., as ADF content of a forage increases, its dry matter digestibility and total digestible nutrients by livestock decreases, in the same way, as NDF content of forage increases, the amount of forage intake by livestock decreases (Schroder, 1994; Sayar, 2014). In the feed, relatively small rises in IVDMD can result in measurable improvements in animal performance (Casler and Jung, 2006).

2.8.3. In sacco degradability

As stated by Osuji *et al*. (1993) the nylon-bag technique provides a means of ranking feeds based on their dry matter, organic matter, nitrogen or other nutritional parameters in relation to the rate and extent of degradation. It encompasses feed samples incubation in the rumens of fistulated animals for periods of 6 to 120 hours and subsequently to determine the disappearance of the different feed components. This technique is appropriate for use by national agricultural research systems because it does not involve large quantities of imported inputs. According to Ørskov (2000), the technique has also provided relatively good predictions of forage intake and digestibility, and it has greatly improved the understanding of nitrogen supply to ruminants and their microbes. However, forage quality varies with species, variety, physiological maturity, regrowth, season, harvesting height, fertilization and other factors (Getnet *et al*., 2008). Rumen degradability of grass and legume species widely varies like the characteristics of other feed due to variations in the genetic makeup of the plants, its environment and stage of growth. In forage plants, significant increase in NDF, ADF and ADL with increased maturity (Kallenbach *et al*., 2002). In general, grasses contain higher concentrations of NDF and ADF than legumes.

2.9. Effect of Season on Availability of Forage

Livestock production is influenced by the seasonal variation of feeds in terms of quantity and quality in Ethiopia. Years of adequate amount and distribution of rainfall enabling production of excess forage but years of poor rainfall result in shortage of forage production to sustain normal development and production in livestock (Alemayehu, 1998). The seasonal pattern of feed supply interacts with the seasonal pattern of feed requirement, for instance those caused by pregnancy, or lactation and to lesser extent, by difference in metabolic requirements due to changing in climatic condition. This is true due to the fact that controlled breeding with seasonal fluctuation of feed supply and demand is not synchronized.

Considerable efforts have been made so far to alleviate the problem of feed shortage in the Ethiopian highlands, aimed at improving feed availability and thereby improve livestock productivity. But, the impact was so insignificant to cope with the problem that livestock are still subjected to nutritional stress in the extended periods especially during the dry seasons (LDMPS, 2006). Grazing of private and communal grasslands was a common practice following the onset of rainfall from late April to early November (Solomon *et al*., 2008). In general, giving due consideration for the quantity and quality of seasonal availability of feed resources is of paramount importance for the development of appropriate strategies and interventions of livestock feeding.

3. MATERIALS AND METHODS

This chapter in general describes information on the study locations, the experimental designs used to layout the field experiments and the experimental treatments assessed. In addition it describes, the laboratory, digestibility (*in vitro* and *in sacco* dry matter) and field research methods employed to gather the data and statistical procedures employed to analyze and summarize the collected data. It has three set of activities (three independent experiments were conducted): Experiment 1-Vetch intercropping and elephant grass spacing; Experiment 2- Harvesting height and nitrogen fertilizer; Experiment 3- Nitrogen fertilizer and plant spacing.

3.1. Descriptions of the Experimental Locations

Experiments were conducted at Holetta and Debre Zeit Agricultural Research Centers of the Ethiopian Institute of Agricultural Research. Holetta Agricultural Research Center (HARC) is situated at an altitude of 2400 masl between 9° 03`N latitude and 38° 30`E longitude in Welmera district in the West Shewa Zone of Oromia Regional States and presented in Figures 1. The rainfall of the area has a bimodal pattern where around 75% falls during the main rainy season (June to September) and the rest 25% (February to May) during the short rainy season. The average maximum and minimum temperatures of Holetta were 24.1^{o}C and 6.4^{o}C, respectively at Holetta. Frost occurs during November to January when the minimum temperature occasionally drops below zero (HARC, 2003). Soils in the area are predominantly nitosols, which are acidic in nature (pH = 5.5) with medium status of fertility (Getachew *et al*. 2006). Debre Zeit Agricultural Research Centre (DZARC) is located at an altitude of 1850 masl between 8^{0} 44` N latitude and 38$^{0}$ 58` E longitude in Adaa district in the East Shewa Zone of Oromia Regional States and presented in Figures 1. It also experiences a bimodal rainfall pattern with a long rainy season (June to October) and a short rainy season (March to May). The average maximum and minimum temperatures of the area were 27.1^{o}C and 11.9^{o}C, respectively.

The Long term (1971-2017) and the experimental period weather data of HARC and DZARC are displayed in Figures 2 and 3. Prior to planting, using soil sampling augur representative soil samples were taken at a depth of 0 - 30 cm layer from the experimental fields. The soil composite samples were analyzed for physico-chemical analysis and the result is presented in Table 1. Soil organic carbon (SOC) content was determined by wet digestion (Walkley, 1947) while total nitrogen was measured by Microkjeldahl method (Bremner and Mulvaney, 1982). Cation exchange capacity (CEC) was determined after ammonium acetate extraction (Van Reeuwijk, 1995). Available phosphorus was measured by the Olsen procedure due to soil samples were with pH <7 (Olsen and Sommers, 1982). Soil pH was determined with an electrode on a 1:2.5 soil – water solution (Hendershot *et al.*, 1993). Soil texture was analyzed using the hydrometer method (Gee and Bauder, 1986).

Table 1. Soil physico-chemical properties from experimental locations at a depth of 0-30 cm at Holetta and Debre Zeit

Loc-ation	pH	P-Available (ppm)	Texture			Textural class	N-Total (%)	OC (%)	OM (%)	CEC (meq/ 100 g soil)	Soil type
			Clay (%)	Sand (%)	Silt (%)						
Holetta	5.19	6.45	66.66	19.16	14.26	Clay	0.19	1.57	2.7	23.33	Nitosol
Debre Zeit	6.24	25.45	61.67	22.5	15.83	Clay	0.14	1.17	2.01	42.42	Vertisol

P = phosphorus; N = nitrogen; OC = organic carbon; OM= organic matter; CEC = cation exchange capacity; ppm = parts per million; meq = milli equivalent; g=gram

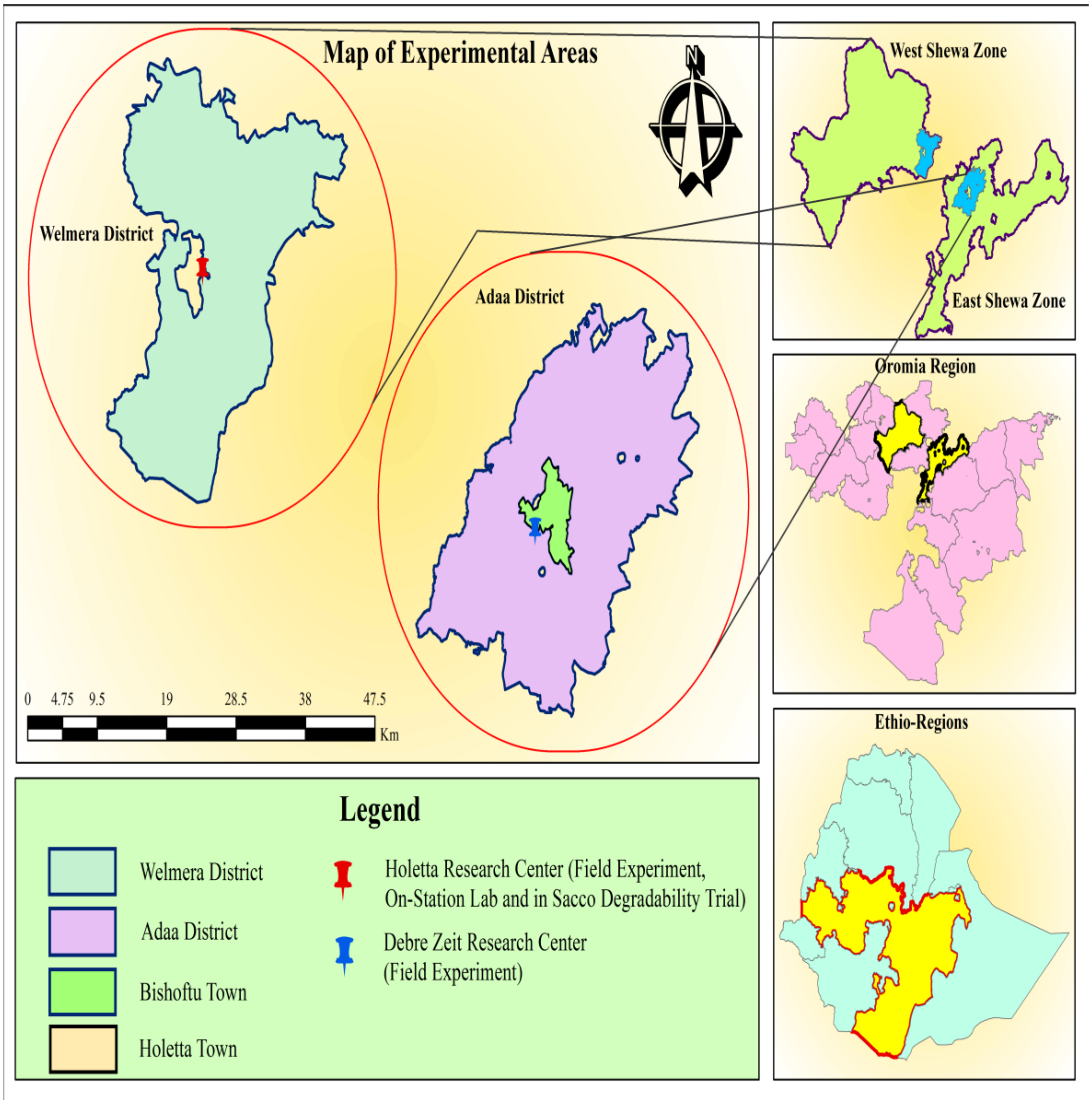
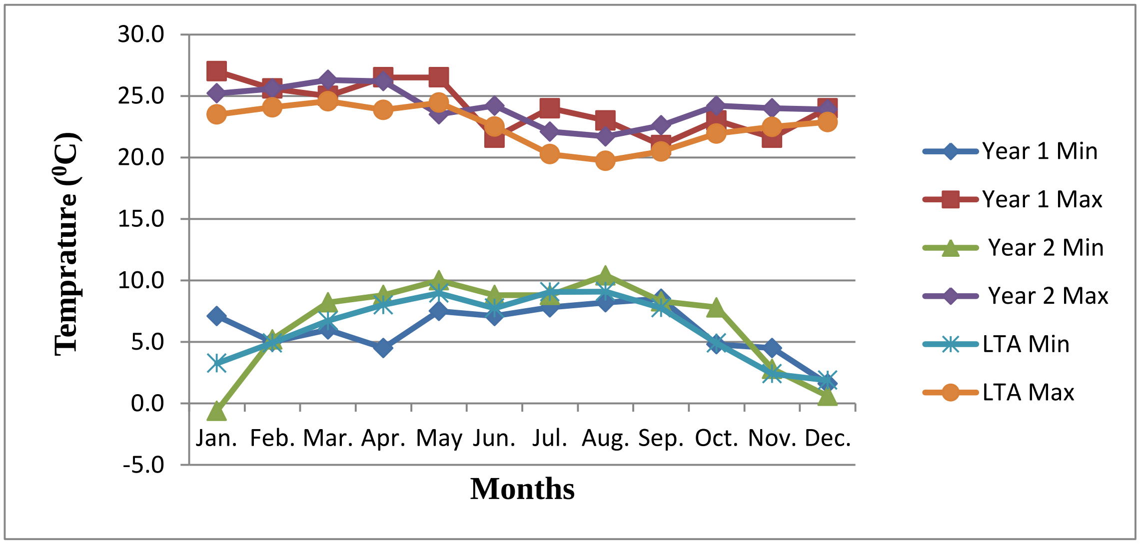
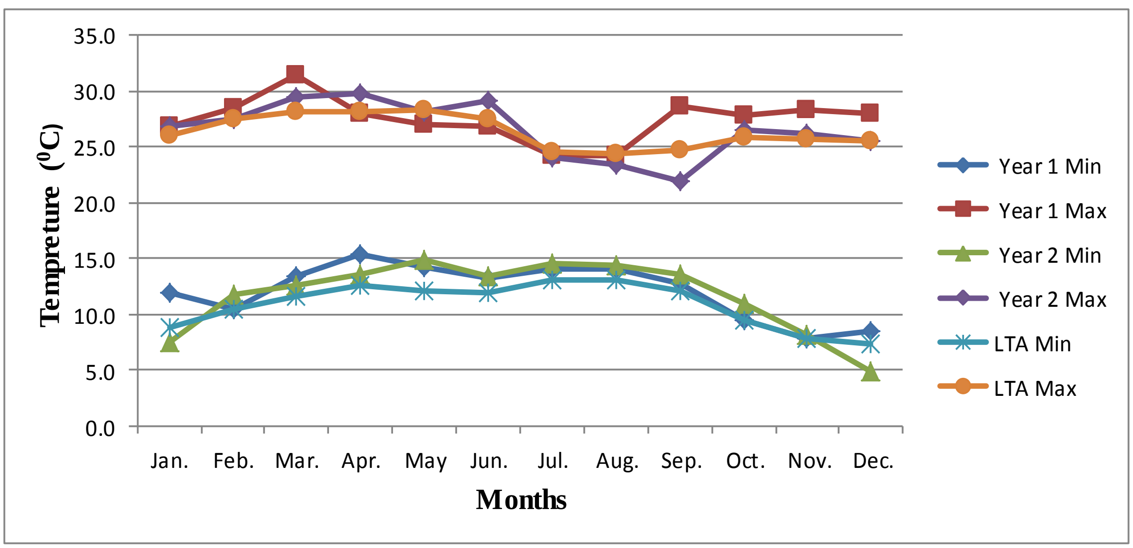


Figure 1. Map showing the experimental locations at Holetta and Debre Zeit agricultural research centers in the central highlands of Ethiopia

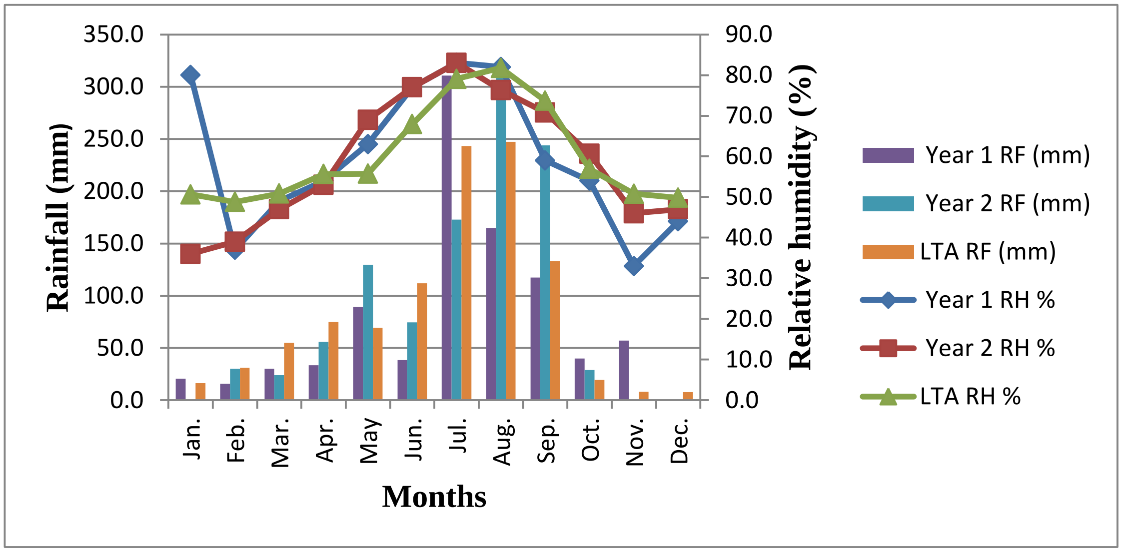


1a) Holetta

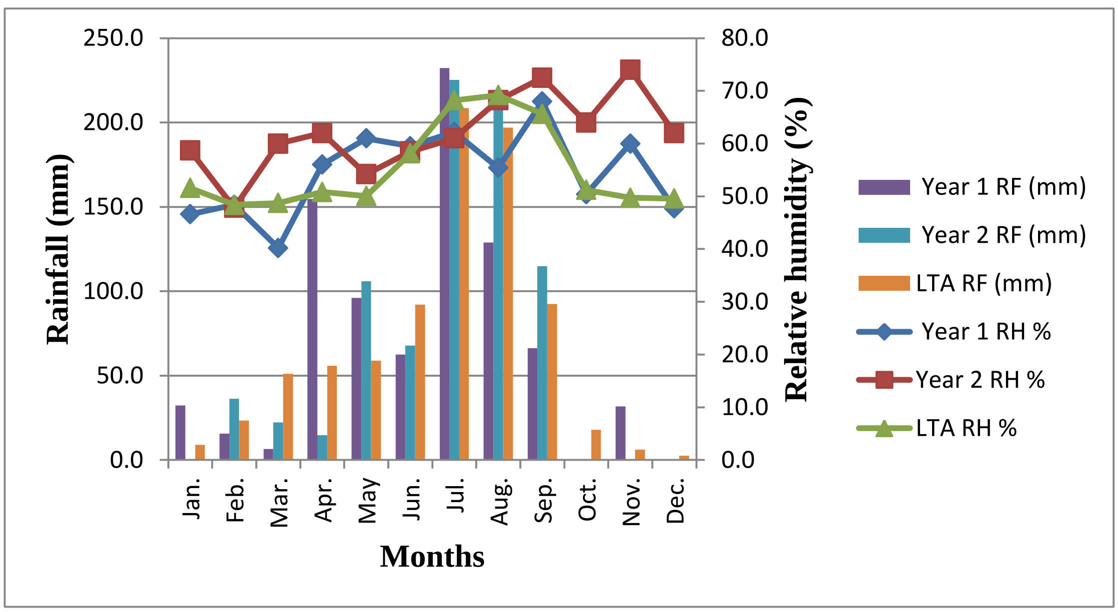


1b) Debre Zeit

Figure 2. Long-term average (LTA) (1971-2017) and during the experimental period (year 1 (2016) and year 2 (2017)) maximum and minimum air temperature (°C) at Holetta (1a) and Debre Zeit (1b)



2a) Holetta



2b) Debre Zeit

Figure 3. Long-term average (LTA) (1971-2017) and experimental period (year 1 (2016) and year 2 (2017)) total annual rainfall (mm) and mean relative humidity (%) at Holetta (2a) and Debre Zeit (2b)

3.2. Field Preparation

The two districts (Welmera and Adaa) were selected purposely based on their dairy farming potential and accessibility. Holetta and Debre Zeit Agricultural Research Centers from Welmera and Adaa districts, respectively were also selected purposely as experimental locations. Both experimental fields were plowed and harrowed using a tractor mounted with moldboard plow and disc harrow to make seedbed with desirable soil tilth in May and June 2016 before plots were laid out and the forages planted. Furthermore, prior to planting, using soil sampling augur soil samples were taken at a depth of 0 to 30 cm layer from the experimental locations.

3.3. Experimental Design and Treatments

3.3.1. Experiment 1- Vetch intercropping and spacing

For experiment 1, 36 plots at Holetta and 36 plots at Debre Zeit with a total of 72 plots with a plot size of 13.5 m^2 (6 m long and 2.25 m wide), were used. The spacing between the plots was 0.5 m and between the replications it was one meter with three replications. The experiment was laid out in a Randomized Complete Block Design (RCBD) with a two factors factorial, with 3x4 arrangements: the 1st factor with three levels' (intercropping/cropping methods) and the 2nd factor with four levels' (plant spacings) described as follows.

a) Three intercropping methods used in the experiment

1) Elephant grass (*Pennisetum purpureum*) pure stand - *ILRI14984*
2) Elephant grass intercropped with vetch - *Vicia dasycarpa*
3) Elephant grass intercropped with vetch - *Vicia villosa*

b) Four spaceings of elephant grass as described in table 2

Table 2. Description of the different spacings used in the experiment

Treatments	**Inter-row Spacing , cm**	**Intra-row Spacing , cm**
S1	75	75
S2	100	50
S3	125	25
S4	50	50

3.3.2. Experiment 2- Harvesting heights of elephant grass and nitrogen fertilizer

For experiment 2, 36 plots at Holetta and 36 plots at Debre Zeit with a total of 72 plots on a plot size of 13.5 m^2 (6 m long and 2.25 m wide) were used. The spacing between the plots was 0.5 m and between the replications it was one meter with three replications. The experiment was laid out in a RCBD with a two factors factorial, with 3x4 arrangements: the 1^{st} factor with three levels' (harvesting heights) and the 2^{nd} factor with four levels' (nitrogen fertilizer rates) with inter and intra row spacing (100 cm x 50 cm) of plant described as follows.

a) Three elephant grass harvesting heights as described in table 3

Table 3. Description of the different harvesting heights used in the experiment

Treatments	**Harvesting height, cm**
Harvesting Height 1 (HH1)	50
Harvesting Height 2 (HH2)	100
Harvesting Height 3 (HH3)	150

b) Four nitrogen fertilization application rates as described in table 4

Table 4. Description of the different nitrogen fertilizer rates used in the experiment two

Treatments	Nitrogen fertilize rates as elemental N , (kg ha^{-1} yr^{-1})
Nitrogen Fertilizer 1 (N1)	0
Nitrogen Fertilizer 2 (N2)	50
Nitrogen Fertilizer 3 (N3)	100
Nitrogen Fertilizer 4 (N4)	150

3.3.3. Experiment 3- Nitrogen fertilizer application rates and spacing

For experiment 3, 48 plots at Holetta and 48 plots at Debre Zeit with a total of 96 plots on a plot size of 13.5 m^2 (6 m long and 2.25 m wide) were used. The spacing between the plots was 0.5 m and between the replications it was one meter with three replications. The experiment was laid out in a RCBD with a two factors factorial, with 4x4 arrangements: the 1st factor with four levels' (nitrogen fertilizer rates) and the 2nd factor with four levels' (plant spacings) with a recommended harvesting height of 1.0 m - 1.5 m described as follows.

a) Four nitrogen fertilizers as described in table 5

Table 5. Description of the different nitrogen fertilizers used in the experiment three

Treatments	Nitrogen fertilizer rates, (kg ha^{-1} yr^{-1})
Nitrogen Fertilizer 1 (N1)	0
Nitrogen Fertilizer 2 (N2)	50
Nitrogen Fertilizer 3 (N3)	100
Nitrogen Fertilizer 4 (N4)	150

b) Four planting spaces of elephant grass as described in table 6

Table 6. Description of the different spacings used in the experiment

Treatments	Spacing between rows, cm	Spacing between plants, cm
S1	75	75
S2	100	50
S3	125	25
S4	50	50

3.4. Planting and Establishment

In experiment 1- vetch intercropping and plant spacing tratments; elephant grasses (*Pennisetum purpureum*) were established using root splits obtained from Holetta research center. It was planted in well-prepared plots in rows S1 (24 root split), S2 (30 root splits), S3 (45 root splits) and S4 (60 root splits)). The material was planted at a depth of 15 - 20 cm with splits planted upright on 1 July 2016 and 14 July 2016 at Holetta and Debre Zeit, respectively on a plot size of 13.5 m^2 (6 m long and 2.25 m wide). Seeds of *V. dasycarpa* and *V. villossa (*the two vetch species) were as well obtained from HARC and sown according to the treatments set-up, at the rate of 25 kg/ha by broadcasting uniformly after three weeks of established elephant grass plots during the establishment year and during the regrowth in the second year after harvesting of elephant grass at the end of June. Using hand hoeing, the sown vetch seeds were mixed with the upper soil layer to facilitate the germination process.

In experiment 2- harvesting heights and nitrogen fertilizer rates, and experiment 3- nitrogen fertilizer rates and plant spacings. The planting materials of elephant grass and nitrogen fertilizer as urea were also obtained from HARC. At the rate of 100 kg ha^{-1} DAP fertilizer (Diammonium Phosphate: 18% N and 46% P_2 O_5) was uniformly applied for all treatment plots at the time of elephant grass planting to enhance better root development at both locations. The nitrogen fertilizer (N) application rates as elemental were applied in two splits (one third at the end of July- two third at the end of August in the establishment year and half at the first week of July - half at the end of August in the second year (regrowths) of establishment) annually in experiments 2 and 3. Hand weeding and hoeing were performed during planting and establishment, and after every elephant grass harvest to facilitate the regrowth.

3.5. Data Collection

3.5.1. Plant height at harvest

In experiment 1- elephant grass and vetch legumes harvesting were made when the vetch species achieved at about 50% of flowering stage. During elephant grass harvesting, each plant consists of a bunch of tillers. Elephant grass and vetch species plant heights were determined by recording an average height of five randomly selected plants per plot prior to harvest. Elephant grass height was measured using a graded measuring stick from the ground level to its highest tip of the main plant or stem. Vetch height was also measured from the ground level to the tip of the plant. The forages were harvested at about 5 to 10 cm height from the ground level manually using sickles. In experiments 2 and 3- elephant grass harvesting was made at the predetermined harvesting height of HH1=50, HH2=100 and HH3=150 cm and within the recommended ranges of 100-150 cm harvesting height, respectively. However, in experiment 2 and 3 during the establishment year, aforementioned recommended harvesting height of elephant grass was not achieved due to the perennial nature of the grass and the cooler central highlands at Holetta. However, at Debre Zeit, the suggested harvesting height reached in both years (during the establishment year (Year 1) and in the regrowth of the second year (Year 2).

3.5.2. Tillering performance

In each of the three experiments- the number of tillers per plant (NTPP) of elephant grass was determined by counting the number of tillers per plant (bunch) and taken as an average number of tillers per plant from five randomly selected plants (bunches) per plot at the time of harvesting during the establishement year and in the regrowth of the second year.

3.5.3. Survival rate

In each of the three experiments- the survival rate (the bunch against to the initially planted root splits) of elephant grass (a bunch considered as one plant) per plot was taken during every harvest in the establishment year and in the regrowth of the second year in order to determine its survival rate as a percentage of the total number of plants initially planted using root splits per plot (S1= 24 root splits per plot (13.5 m^2) = plant density= 17, 778 plants/ha), S2= 30 root splits (22, 222 plants/ha), S3= 45 root splits (33, 333 plants/ha) and S4= 60 root splits (44, 444 plants/ha) were used. In short, the survival rate percentage of elephant grass was determined as the proportion of a number of living plants (a bunch considered as one plant) per plot to the initially planted total number of plants using root splits per plot and then multiplied it by hundred (100).

3.5.4. Forage yield

In each of the three experiments- the harvested fresh forage weight from each plot was determined using field balance. Fresh subsamples of 900 g forage were as well taken from each plot and plant species separately. The forage subsamples of elephant grass were chopped and shredded to facilitate the drying process. Drying of forage subsamples was performed using a forced air draft oven at 65^0C for 72 hours (to constant weight). Dry matter percentage was estimated by dividing the dried weight of forage subsample by the fresh weight of subsample and multiplied it by hundred. The dry matter yield (DMY) was determined using the following formula.

DMY (t/ha) = TFW x (DWss /HA x FWss) x 10; Where TFW = total fresh weight kg/plot; DWss = dry weight of subsample in grams; FWss = fresh weight of subsample in grams; HA = Harvest plot area in square meters and 10 is a constant for conversion of yields in kg/m^2 to t/ha.

3.5.5. Leaf to stem ratio

In each of the three experiments an average leaf to stem ratio (LSR) of elephant grass was determined by harvesting randomly selected five plants per plot and partitioning into leaf (leaf sheath included in the leaf fraction) and stem fractions for each plot and experiment. The fresh subsamples of elephant grass leaf and stem were separately weighed and dried using an oven at 65^{0}C to constant weights and the LSR was determined by dividing the leaf dry weight by the stem dry weight of elephant grass.

3.5.6. Dry matter percentage

In each of the three experiments- dry matter percentage was estimated by dividing the dried weight of forage (elephant grass and vetch legumes) subsamples by the fresh weight of subsamples and multiplied it by hundred. Drying was done using a forced air draft oven using the procedures described above for the forage dry matter yield determinations.

3.5.7. Grass – legume proportions

In experiment 1- Grass – legume proportions for chemical composition, *in vitro* dry matter digestibility and *in sacco* dry matter degradability were determined based on the percentage of elephant grass and vetch legume species dry matter yields in each plot forage mixtures (total) dry matter yield.

3.6. Forage Quality Measurements

3.6.1. Chemical analysis of feed samples

Samples of forage from each experiment, 1, 2 and 3 were harvested and chopped to a size of 3-5 cm and dried in air draft oven at 65^{o}c for 72 hours (to constant weight) and maintained for chemical analysis being packed in paper bags at room temperature. The dried forage subsamples then ground to pass through 1 mm screen using Wiley mill for chemical anaysis. For experiments 1 and 2, the DM and ash contents were determined by oven drying at 105°C overnight and combusting in a muffle furnace at 500°C for 6 hours, respectively (AOAC, 1990). The nitrogen (N) content was determined by Kjeldahl method and CP was calculated as N x 6.25 (AOAC, 1995). According to the methods of Van Soest and Robertson (1985), the neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined.

For experiment 3, the chemical composition (DM, ash, CP, NDF, ADF, ADL) was determined using a calibrated near infra-red reflectance spectroscopy (NIRS) apparatus available at Holetta Agricultural Research Center. The NIRS procedure was performed on 3 g of ground sample using Foss NIRS 5000 in the 1108 – 2492 spectral range with an 8 nanometer step. Prior to scanning, the samples were pre-dried at 60^{o}C overnight in a forced air draft oven to normalize moisture conditions. Each sample spectra were taken by scanning for three consecutive times (Win Scan 1.5, 2000 Infrasoft International) (Dereje *et al*., 2010). The chemical analysis was conducted at Holetta Agricultural Research Center (HARC).

3.6.2. In vitro dry matter digestibility determination

In vitro dry matter digestibility (IVDMD) of experiments 1 and 2 was determined by using the two-stage rumen inoculum pepsin method of Tilley and Terry (1963). Dried feed samples were ground to pass through a 1 mm screen for IVDMD determination. Duplicate samples of about 0.5 g each were incubated with 30 ml of rumen liquor in 100 ml test tube in water bath at 39^0C for a period of 48 hours for microbial digestion. These were followed by another 48 hours for enzyme digestion with acid pepsin solution. Blank samples containing buffered rumen fluid only were also incubated in duplicate for adjustment. Drying of samples residues was done at 105^0C for 24 hours. The IVDMD was calculated as dry sample weight- (residue- blank) / dry sample weight x 100. However, the IVDMD of experiment 3- was determined using a calibrated near infra-red reflectance spectroscopy (NIRS) apparatus available at Holetta Agricultural Research Center. The NIRS procedure was performed on 3 g of ground sample using Foss NIRS 5000 in the 1108 – 2492 spectral range with an 8 nanometer step. Prior to scanning, the samples were pre-dried at 60^oC overnight in a forced air draft oven to normalize moisture conditions. Each sample spectra were taken by scanning for three consecutive times (Win Scan 1.5, 2000 Infrasoft International) (Dereje *et al*., 2010). The *in vitro* dry matter digestibility was conducted at Holetta Agricultural Research Center.

3.6.3. In sacco dry matter degradability determination

In experiment 1, Year 1 forage samples and in experiment 2, Year 2 samples were used to determine *in sacco* dry matter (DM) degradability of elephant grass in both locations. Furthermore, for experiment 1, vetch intercropping (vetch legumes intercropped with elephant grass and pure stand elephant grass) with a spacing of 50 cm between rows and plants and for experiment 2, elephant grass harvesting height (HH1, HH2 and HH3) with N3 in two split applications annually per treatments were selected and used for *in sacco* DM degradability of forages based on their dry matter yield (DMY), crude protein (CP) content and *in vitro* dry matter digestibility (IVDMD). The *in sacco* DM degradability was determined by incubating 3 g of ground each feed samples in a Willey mill to pass through 2 mm sieve size in duplicate nylon bags with a dimension of 9 cm x 14 cm and a pore size of 40-50 µm using 3 rumen-fistulated crossbred (Boran x Fresian) steers weighing approximately 550 ± 15 kg, each kept under maintenance ration at Holetta Agricultural Research Center. The steers were managed in door and were offered *ad libitum* natural pasture hay (6.8% CP) supplemented with 2 kg concentrate per head per day on DM basis. The concentrate has a mixture of 63% wheat bran, 36% noug seed cake (*Guzotia abyssinica*) and 1% salt. Water was as well provided free choice. Rumen degradability of the samples was determined by incubating at 6, 12, 24, 48, 72 and 96 hours. Immediately on removal from the rumen, the bags including zero hour was rinsed thoroughly under running tap water and washed manually until clear water appeared at the end. Then these bags were dried in a forced-draught oven at 65^0C for 72 hours (constant weight). Washing losses was determined by soaking duplicate bags per sample in cold tap water for about half an hour and washed in a similar procedure as that of the incubated bags. The dried bags were taken out of the oven and dry weights were recorded. The residues were then pooled for each animal by incubation time and the degradability of DM was determined. The degradability was measured in terms of disappearance of DM and expressed as percentage.

$$\text{Dry matter disappearance (DMD)} = \frac{((BW+S1DM1) - (BW+RW))}{(S1 \times DM1)} \times 100$$

Where; BW = Empty Bag weight; RW = Dried Residue weight; S1 = Sample weight; DM1 = Dry matter content of the original sample.

The degradability constants were fitted in to the exponential equations as described by Ørskov and McDonald (1979), using the Neway Excel program (Chen, 1995). $P = a+b\,(1-e^{-ct})$; where P = the potential disappearance of dry matter at time t; a = rapidly degradable or water soluble fraction; b = the potentially, but slowly degradable fraction; c = the rate of degradation of b; e = the natural logarithm and t = the incubation time (hour). Potential degradability (PD) was estimated as (a+ b), while effective degradability (ED) was calculated according to Dhanoa (1988) using the formula ED = a + [bc/ (k+c)] at rumen outflow rate (k) of 3%/h.

3.7. Statistical Models and Data Analysis

In experiment 1,- vetch intercropping and plant spacing data on forage agronomic performances and quality traits were subjected to model A: $Y_{ijklm} = \mu + B_i + I_j + S_k + L_l + H_m + (I*S)_{jk} + e_{ijklm;}$ where Y_{ijklm} = the measured response, μ = the overall mean; B_i= the effect of the i^{th} block; I_j = the effect of the j^{th} vetch intercropping (j= 3); S_k= the effect of the k^{th} spacing (k=4); L_l = the effect of the l^{th} location (l= 2); H_m = the effect of m^{th} year of harvesting (m= 2); $(I*S)_{jk}$= the interaction effect of vetch intercropping and plant spacing; e_{ijklm} = the random error.

The nylon bag data analysis over locations for year 1 forage samples was subjected to model B: $Yijk = \mu + I_i + ßj + L_k + (I*L)_{ik} + e_{ijk}$, where; μ = overall mean; I = vetch intercropping effect; ßj = replication (animals) effect; L_k = location effect; $(I*L)_{ik}$ = interaction effect of vetch intercropping and location; eijk = the random error.

In experiment 2, nitrogen fertilizer and harvesting height data on forage agronomic performances were subjected to model A: $Y_{ijklm} = \mu + B_i + HH_j + N_k + L_l + H_m + (HH*N)_{jk} + e_{ijklm;}$ where Y_{ijklm} = the measured response, μ = the overall mean; B_i= the effect of the i^{th} block; HH_j= the effect of the j^{th} harvesting height (j=3); N_k = the effect of the k^{th} nitrogen fertilizer (k= 4); L_l = the effect of the l^{th} location (l= 2); H_m = the effect of m^{th} year of harvesting (m= 2); $(HH*N)_{jk}$= the interaction effect of harvesting height and nitrogen fertilizer; e_{ijklm} = the random error.

Forage DM and CP yields, and quality traits data were subjected to model B: $Y_{ijklm} = \mu + B_i + HH_j + N_k + L_l + (HH*N)_{jk} + e_{ijklm;}$ where Y_{ijklm} = the measured response, μ = the overall mean; B_i= the effect of the ith block; HH_j= the effect of the jth harvesting height (j=3); N_k = the effect of the kth nitrogen fertilizer (k= 4); L_l = the effect of the lth location (l= 2); $(HH*N)_{jk}$= the interaction effect of harvesting height and nitrogen fertilizer; e_{ijklm} = the random error.

The nylon bag data analysis over locations from year 2 forage samples was subjected to model C: $Y_{ijk} = \mu + HH_i + ß_j + L_k + (HH*L)_{ik} + e_{ijk}$, where; μ = overall mean; HH = harvesting height effect; ßj = replication (animals) effect; L_k = location effect; $(HH*L)_{ik}$ = interaction effect of harvesting height and nitrogen fertilizer; e_{ijk} = the random error.

In experiment 3, nitrogen fertilizer and plant spacing data on forage agronomic performances were subjected to model A: $Y_{ijklm} = \mu + B_i + N_j + S_k + L_l + H_m + (N*S)_{jk} + e_{ijklm}$; where Y_{ijklm} = the measured response, μ = the overall mean; B_i= the effect of the ith block; N_j= the effect of the jth nitrogen fertilizer (j=4); S_k = the effect of the kth spacing (k= 4); L_l = the effect of the lth location (l= 2); H_m = the effect of mth year of harvesting (m= 2); $(N*S)_{jk}$= the interaction effect of nitrogen fertilizer and plant spacing; e_{ijklm} = the random error.

For forage DM and CP yields, and quality traits were subjected to model B: $Y_{ijklm} = \mu + B_i + N_j + S_k + L_l + (N*S)_{jk} + e_{ijklm}$; where Y_{ijklm} = the measured response, μ = the overall mean; B_i= the effect of the ith block; N_j= the effect of the jth nitrogen fertilizer (j=4); Sk = the effect of the kth spacing (k= 4); L_l = the effect of the lth location (l= 2); $(N*S)_{jk}$= the interaction effects of nitrogen fertilizer and plant spacing; e_{ijklm} = the random error.

All data was collected from the field, laboratory and *in sacco* dry matter degradability based experiments were subjected to analysis of variance using the general linear model' (GLM) procedures of Statistical Analysis System, version 9.1 (SAS, 2002). Least significance difference (LSD) at 5% significance level was used for comparison of means.

4. RESULTS

This section is divided into three parts. In experiment 1, results from evaluation of the agronomic performances of elephant grass, subsequent dry mater yield, chemical composition, *in vitro* dry matter digestibility and *in sacco* dry matter degradability as affected by vetch intercropping and different plant spacing are presented. Data on agronomic performances of elephant grass, subsequent dry mater yield, crude protein yield, chemical composition, *in vitro* dry matter digestibility and *in sacco* dry matter degradability of elephant grass forage as influenced by harvesting height and nitrogen fertilizer rates are presented in experiment 2. In experiment 3, the effet of different nitrogen fertilizer rates application and plant spacing on agronomic performances of elephant grass, dry mater yield, crude protein yield, chemical composition, and *in vitro* dry matter digestibility were evaluated.

4.1. Experiment 1- Intercropping of Vetch with Elephant Grass and Plant Spacing

4.1.1. Agronomic performances of elephant grass

4.1.1.1. Survival rate of elephant grass

The effects of vetch intercropping and plant spacing on the survival rate percentage of elephant grass during the first establishment year (Year 1) and in the regrowth during the second year (Year 2) are given in Table 7. The survival rate of elephant grass was significantly ($P<0.05$) affected by vetch intercropping over years and locations. Higher survival rate was recorded in pure stand elephant grass than vetch species intercropped with elephant grass. The effect of vetch (*Vicia dasycarpa* and *Vicia villosa)* intercropping reduced the survival rate of elephant grass by 7.4 and 27.6%, respectively as compared to the pure stand elephant grass over years and locations.

The survival rate of elephant grass was considerably (P< 0.05) affected by plant spacing of the combined data analysis over years at Holetta, and combined over years and locations revealed. Comparable and higher values were recorded at a wider plant spacing of S2 (100 cm x 50 cm) and S1 (75 cm x 75 cm) than narrower spacings of S3 (125 cm x 25 cm) and S4 (50 cm x 50 cm) at Holetta and combined over years and locations. The overall average survival rate of elephant grass was found to be 59.4%.

Table 7. Mean survival rate of elephant grass during the establishment year (Year 1) and in the regrowth during the second year (Year 2) (% survived from the initial number of root splits planted) as affected by vetch intercropping and plant spacing (combined over years and locations)

Treatment	**Holetta**	**Debre Zeit**	**Year 1**	**Year 2**	**Mean**
Vetch Intercropping (I)					
Pure stand Elephant G	75.7^{a}	55.5^{a}	68.4^{a}	62.8^{a}	65.6^{a}
Elephant G + *V. dasycarpa*	71.6^{a}	50.6^{a}	63.0^{a}	59.2^{a}	61.1^{b}
Elephant G + *V. villosa*	61.4^{b}	41.3^{b}	54.0^{b}	48.8^{b}	51.4^{c}
P-value	0.0001	0.0002	0.0001	0.0006	0.0001
Plant Spacing (S), cm					
S1 (75 x 75)	70.5^{ab}	52.0	64.4	58.1	61.2^{ab}
S2 (100 x 50)	74.8^{a}	50.6	65.4	60.0	62.7^{a}
S3 (125 x 25)	68.3^{b}	45.5	60.1	53.7	56.9^{b}
S4 (50 x 50)	64.7^{b}	48.6	57.3	55.8	56.6^{b}
Mean	69.6	49.2	61.8	56.9	59.4
SEM	0.35	0.40	0.38	0.41	0.28
CV (%)	12.70	23.29	16.45	21.21	18.69
I*S	NS	NS	NS	NS	NS
P-value	0.0095	0.3644	0.0730	0.4364	0.0472

$^{a-c}$ Means followed by different superscripts within a column are significantly different (P<0.05); S1= 24 root splits of elephant grass per plot (13.5m^{2}) planted initially; S2= 30 root splits per plot; S3= 45 root splits per plot; S4=60 root splits per plot; Elephant G = elephant grass; Year 1= 2016 harvesting; Year 2= 2017 harvesting; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

4.1.1.2. Tillering performance of elephant grass

Table 8 shows the number of tillers produced per plant in elephant grass during establishment year and in the regrowth during the second year. In vetch intercropping at different plant spacing, the number of tillers per plant was not significantly ($P > 0.05$) affected by vetch intercropping, except the combined analysis of over locations in year 1 ($P < 0.05$). In the first year, considerably higher number of tillers per plant was recorded in *Vicia dasycarpa* (19.8) and *Vicia villosa* (18.6) intercropping with elephant grass than pure stand elephant grass (18.0) in year 1. The mean tiller numbers produced per plant of elephant grass (Holetta vs Debre Zeit) was 32.1 vs 44.3, 32.9 vs 47.5 and 32.0 vs 48.0 for pure stand elephant grass, *Vicia dasycarpa* and *Vicia villosa* intercropping, respectively. On the other hand, mean tiller numbers yielded per plant of elephant grass (Year 1 vs Year 2) were 18.0 vs 58.3, 19.8 vs 60.6 and 18.6 vs 61.9 for pure stand elephant grass, *Vicia dasycarpa* and *Vicia villosa* intercropping, respectively.

The number of tillers produced was significantly ($P < 0.05$) affected by spacing both at Holetta and Debre Zeit. The effect of spacing on tillering did not show significant effect during the establishment year (Year 1), however, the regrowth tillering in the second year (Year 2) showed significant differences ($P<0.05$). The highest number of tillers per single elephant grass was recorded at a wider plant spacing S1 (75 cm x 75 cm) followed by S2 (100 cm x 50 cm), S3 (125 cm x 25 cm) and the lowest was recorded at a narrow spacing of S4 (50 cm x 50 cm) at Holetta. In the second year of regrowth, the plant develops so tillering is high although it is enhanced by wider elephant grass spacing. At Debre Zeit, in year 2 and the combined analysis over years and locations more or less similar trends were observed.

Table 8. Mean number of tillers per plant (NTPP) of elephant grass during the establishment year (Year 1) and in the regrowth during the second year (Year 2) grass as affected by vetch intercropping and plant spacing (combined over years and locations)

Treatment	**Holetta**	**Debre Zeit**	**Year 1**	**Year 2**	**Mean**
Vetch Intercropping (I)					
Pure stand Elephant G	32.1	44.3	18.0^{b}	58.3	38.2
Elephant G + *V. dasycarpa*	32.9	47.5	19.8^{a}	60.6	40.2
Elephant G + *V. villosa*	32.4	48.0	18.6^{ab}	61.9	40.2
P-value	0.7981	0.3832	0.0350	0.5285	0.3363
Plant Spacing (S), cm					
S1 (75 x 75)	36.7^{a}	49.2^{a}	19.5	66.3^{a}	42.9^{a}
S2 (100 x 50)	32.5^{b}	45.4^{ab}	18.6	59.3^{ab}	38.9^{b}
S3 (125 x 25)	30.6^{b}	51.5^{a}	18.8	63.3^{a}	41.1^{ab}
S4 (50 x 50)	30.2^{b}	40.4^{b}	18.3	52.2^{b}	35.3^{c}
Mean	32.5	46.6	18.8	60.3	39.5
SEM	0.25	0.38	0.18	0.39	0.23
CV (%)	13.55	21.78	12.81	18.13	19.81
I*S	NS	NS	NS	NS	NS
P-value	0.0001	0.0099	0.5225	0.0023	0.0006

a-c Means followed by different superscripts within a column are significantly different ($P<0.05$); Elephant G = elephant grass; Year 1= 2016 harvesting; Year 2= 2017 harvesting; SEM= standard error of mean; CV= coefficient of variation; NS= non-significant

4.1.1.3. Plant height of elephant grass and vetch species legumes at harvest

Plant height (PH) of elephant grass and vetch species (*Vicia villosa* and *Vicia dasycarpa*) at the optimum harvesting stage of vetch (50% flowering) is presented in Table 9. Vetch intercropping and spacing of elephant grass did not have significant (P>0.05) effect on the height of elephant grass and vetch species forages with the exception of vetch species in the combined analysis over locations at different plant spacing. The highest plant height of vetch species was recorded at S4 (50 cm x 50 cm) and the lowest was measured S2 (100 cm x 50 cm), while the rest of spacings S1 (75 cm x 75 cm) and S3 (125 cm x 25 cm) having intermidate values between the above two. Elephant grass did not attain the recommended harvesting height (1.0 m to 1.5 m) during the establishment year (Year 1 harvesting) at Holetta. This finding was expected owing to its slow rate of growth in cool highlands such as Holetta during the establishment year. However, at Debre Zeit, the aforementioned recommended harvesting height (1.0 m to 1.5 m) was achieved in both the establishment year and the second year of establishment due to warmer environmental conditions in the area. The combined analysis over locations resulted in a total mean height of elephant grass and vetch species 98.5 cm and 140.3 cm, respectively.

Table 9. Mean plant height (cm) of elephant grass and vetch species at the optimum harvesting stage of vetch (50% flowering) as affected by vetch intercropping and plant spacing (combined over years at each location)

Treatment	Holetta		Debre Zeit		Mean	
	Elephant grass	Vetch	Elephant grass	Vetch	Elephant grass	Vetch
Vetch Intercropping (I)						
Pure stand Elephant G	91.1	-	103.6	-	97.3	-
Elephant G+ *V. dasycarpa*	97.9	147.8	100.9	130.5	99.4	139.1
Elephant G + *V. villosa*	94.4	149.4	103.1	133.6	98.8	141.5
P-value	0.0814	0.6665	0.4436	0.5270	0.5579	0.4492
Plant Spacing (S), cm						
S1 (75 x 75)	94.8	145.3	100.9	126.8	97.8	136.0^{bc}
S2 (100 x 50)	94.4	145.9	102.1	124.5	98.3	135.2^{c}
S3 (125 x 25)	93.7	147.3	106.4	141.5	100.1	144.4^{ab}
S4 (50 x 50)	94.7	156.0	100.1	135.4	97.8	145.7^{a}
Mean	94.4	148.6	102.6	132.1	98.5	140.3
SEM	0.38	0.53	0.33	0.59	0.28	0.40
CV (%)	10.97	9.08	7.57	12.50	9.69	10.85
I*S	NS	NS	NS	NS	NS	NS
P-value	0.9896	0.1930	0.1176	0.0577	0.7178	0.0327

$^{a-c}$ Means followed by different superscripts within a column are significantly different (P<0.05); Elephant G =elephant grass; SEM=standard error of the mean; CV= coefficient of variation; NS= non-significant

4.1.1.4. Leaf to stem ratio of elephant grass

The effect of vetch intercropping, and plant spacing of elephant grass on the leaf to stem ratio (LSR) of elephant grass is presented in Table 10. Vetch intercropping significantly ($P<0.05$) affected on the LSR at both the locations and years as well as in the combined analysis over years and locations. Higher LSR of elephant grass was recorded in vetch (*V. villosa* and *V. dasycarpa*) intercroppings with elephant grass than pure stand elephant grass, with a mean of 2.53 at Holetta and 1.88 at Debre Zeit.

Plant spacing did also significantly ($P<0.05$) affect the LSR of elephant grass at Debre Zeit and in the combined analyses over years and locations. Higher LSR value was recorded at a wider plant spacing of S1 (75 cm x 75 cm) than the other spacings of S2 (100 cm x 50 cm), S3 (125 cm x 25 cm) and S4 (50 cm x 50 cm) in the combined analysis over years at Debre Zeit (2.11 LSR highest; 1.75 LSR lowest). In the combined analysis over years and locations, the highest value was recorded at a wider plant spacing of S1 (75 cm x 75 cm) followed by S2 (100 cm x 50 cm) and S4 (50 cm x 50 cm), while the lowest LSR was recored at a spacing of S3 (125 cm x 25 cm), with the highest and the lowest values 2.37; 2.08, respectively with an overall mean value (2.21) of elephant grass. The interaction of vetch intercropping and plant spacing significantly ($P<0.05$) affected the LSR of elephant grass except at Debre Zeit and in year 2.

Table 10. Mean leaf to stem ratio (LSR) of elephant grass at the optimum harvesting stage of vetch (50% flowering) during the establishment year (Year 1) and in the regrowth during the second year (Year 2) as affected by vetch intercropping and plant spacing (combined over years and locations)

Treatment	**Holetta**	**Debre Zeit**	**Year 1**	**Year 2**	**Mean**
Vetch Intercropping (I)					
Pure stand Elephant G	2.33^{b}	1.65^{b}	2.34^{b}	1.64^{b}	1.99^{b}
Elephant G + *V. dasycarpa*	2.55^{ab}	1.95^{a}	2.68^{a}	1.86^{a}	2.25^{a}
Elephant G + *V.villosa*	2.71^{a}	2.04^{a}	2.89^{a}	1.82^{a}	2.38^{a}
P-value	0.0345	0.0005	0.0025	0.0022	0.0001
Plant Spacing (S)					
S1 (75 x 75)	2.63	2.11^{a}	2.92	1.82	2.37^{a}
S2 (100 x 50)	2.56	1.80^{b}	2.59	1.77	2.18^{ab}
S3 (125 x 25)	2.41	1.75^{b}	2.44	1.71	2.08^{b}
S4 (50 x 50)	2.53	1.86^{b}	2.59	1.77	2.20^{ab}
Mean	2.53	1.88	2.64	1.77	2.21
SEM	0.083	0.068	0.085	0.055	0.053
CV (%)	19.69	17.85	19.53	12.38	18.41
I*S	0.0396	NS	0.0164	NS	0.0035
P-value	0.6240	0.0103	0.0528	0.5082	0.0280

[a-b] Means followed by different superscripts within a column are significantly different (P<0.05); Elephant G = elephant grass; Year 1= 2016 harvesting; Year 2= 2017 harvesting; I= vetch intercropping; S= plant spacing; I*S= interaction of vetch intercropping and plant spacing; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

4.1.1.5. Dry matter yields of elephant grass and vetch species

The dry matter yields of vetch intercropping was significantly (P<0.05) varied in the combined analysis over years and locations (Table 11), except at Debre Zeit. Higher DM yields were produced in vetch intercropping than in pure stand elephant grass combined over years and locations. Furthermore, *Vicia dasycarpa* and *Vicia villosa* intercropping produced comparable and significantly (P<0.05) higher DM yield than pure stand elephant grass in the combined analysis over years and locations. The overall mean DM yield of vetch intercropping was higher at Debre Zeit than at Holetta. Harvesting year also affected the DM yield of vetch intercropping and the overall mean DM yields were 8.03 and 14.39 t/ha in year 1 and 2, respectively. In general, at Holetta, *V. dasycarpa* and *V. villosa* intercropping produced 67.1 and 72.9% DM yield advantages over the pure stand elephant grass, respectively. In the same way at Debre Zeit, *V. dasycarpa* and *V. villosa* intercropping yielded 11.0 and 6.0% more DM yield advantages than the pure stand elephant grass, respectively. As shown in Table 12, in vetch intercropping treatment the DM yield of vetch species significantly (P<0.05) varied over years and locations. The DM yield of *V. villosa* was significantly (P<0.05) higher than *V. dasycarpa.*

The DM yield of vetch intercropping significantly (P<0.05) varied at different plant spacings of elephant grass. Total dry matter yields of pure stand elephant grass and vetch intercropping showed an increasing trend with increasing plant density indicating: S1< S2< S3< S4. Furthermore, S4 (50 cm x 50 cm) at narrower spacing of elephant grass resulted in 17.6, 22.8 and 25.6% more DM yield advantages than S3 (125 cm x 25 cm), S2 (100 cm x 50 cm) and S1 (75 cm x 75 cm), respectively. Generally, pure stand elephant grass and vetch intercropping combined over years were produced higher DM yield at Debre Zeit than at Holetta. These could be associated with the warm weather condition at Debre Zeit which supports fast growth and higher DM production of elephant grass. However, the different spacings of elephant grass did not significantly (P>0.05) affect the DM yield of vetch species (Table 12).

Table 11. Mean total annual forage dry matter yield (DMY, t/ha) of elephant grass + vetch species during the establishment year (Year 1) and in the regrowth during the second year (Year 2) as affected by vetch intercropping and plant spacing (cm) (combined over years and locations)

Treatment	Holetta			Debre Zeit			Mean combined over locations		Overal1 Mean
	Year 1	Year 2	Mean	Year 1	Year 2	Mean	Year 1	Year 2	
Vetch Intercropping (I)									
Pure stand Elephant G	1.82[c]	9.98	5.90[b]	10.46	15.60	13.03	6.14[b]	12.78[b]	9.47[b]
Elephant G + *V. dasycarpa**	7.87[b] (83.9)	11.85 (2.4)	9.86[a] (35.0)	9.30 (32.8)	19.63 (2.2)	14.46 (12.0)	8.58[a] (56.2)	15.74[a] (2.3)	12.16[a] (21.3)
Elephant G + *V. villosa**	9.10[a] (90.2)	11.31 (3.6)	10.20[a] (42.3)	9.64 (44.8)	17.97 (2.9)	13.81 (17.5)	9.37[a] (66.9)	14.64[ab] (3.2)	12.01[a] (28.1)
P-value	0.0001	0.1343	0.0001	0.3081	0.1385	0.4111	0.0001	0.0374	0.0001
Plant Spacing (S)									
S1 (75 x 75)	6.06 (80.8)	10.87 (2.1)	8.46 (45.4)	7.95[c] (36.1)	16.39 (1.9)	12.17[b] (19.6)	7.00[c] (83.1)	13.63 (3.0)	10.32[b] (30.1)
S2 (100 x 50)	5.70 (70.0)	10.25 (2.4)	7.98 (45.0)	8.88[bc] (27.7)	17.36 (2.2)	13.12[b] (16.2)	7.29[c] (72.0)	13.81 (3.4)	10.55[b] (27.1)
S3 (125 x 25)	6.21 (76.5)	10.48 (2.1)	8.35 (44.8)	10.61[ab] (19.0)	16.76 (1.9)	13.68[ab] (12.9)	8.41[b] (60.4)	13.62 (3.0)	11.02 [b] (25.0)
S4 (50 x 50)	7.09 (78.0)	12.59 (1.7)	9.84 (45.9)	11.77[a] (21.0)	20.41 (1.3)	16.09[a] (12.7)	9.43[a] (64.1)	16.50 (2.2)	12.96[a] (24.47)
Mean	6.26	11.05	8.65	9.8	17.73	13.77	8.03	14.39	11.21
SEM	0.177	0.251	0.17	0.228	0.364	0.23	0.14	0.23	0.142
CV (%)	18.04	20.51	25.2	19.13	27.11	26.79	18.38	26.97	26.06
I*S	0.0001	NS	NS	0.0095	NS	NS	NS	NS	NS
P-value	0.0853	0.1426	0.0668	0.0008	0.2929	0.0163	0.0001	0.0827	0.0008

[a-c] Means followed by different superscripts within a column are significantly different (P<0.05); *Figures in parenthesis are percentage of vetch species DMY from the total DMY (Elephant grass + Vetch species); SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

Table 12. Mean annual forage dry matter yield (t/ha) of vetch species during the establishment year (Year 1) and in the regrowth during the second year (Year 2) as affected when intercropped in elephant grass planted at different spacings (combined over years and locations)

Treatment	Location		Year		Mean
	Holetta	Debre Zeit	Year 1	Year 2	
Vetch Intercropping (I)					
Pure stand Elephant G.	-	-	-	-	-
Elephant G + *V. dasycarpa*	3.45[b]	1.74[b]	4.83[b]	0.36[b]	2.59[b]
Elephant G + *V. villosa*	4.31[a]	2.42[a]	6.27[a]	0.47[a]	3.37[a]
P-value	0.0024	0.0011	0.0001	0.0008	0.0001
Plant Spacing (S), cm					
S1 (75 x 75)	3.84	2.39	5.82	0.41	3.11
S2 (100 x 50)	3.59	2.13	5.25	0.47	2.86
S3 (125 x 25)	3.74	1.76	5.08	0.41	2.75
S4 (50 x 50)	4.35	2.05	6.04	0.36	3.20
Mean	3.88	2.08	5.55	0.41	2.98
SEM	0.139	0.119	0.139	0.047	0.084
CV (%)	23.86	32.48	16.76	25.55	22.58
I*S	NS	NS	NS	NS	NS
P-value	0.2199	0.1658	0.0523	0.1032	0.0778

[a-b] Means followed by different superscripts with in a column are significantly different (P<0.05); Elephant G = elephant grass; Year 1= 2016 harvesting; Year 2= 2017 harvesting; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

4.1.2. Forage chemical composition and in vitro dry matter digestibility

Chemical composition (CP, ash, NDF, ADF, and ADL) and *in vitro* dry mater digestibility (IVDMD) of elephant grass as affected by vetch intercropping and plant spacing during the establishement year and in the regrowth during the second years are presented in Tables 13 to 18. Comparable and significantly ($P<0.05$) higher CP content was recorded in vetch *(V. dasycarpa and V. villosa)* intercropping than pure stand elephant grass at Holetta, Debre

Zeit, in year 1 and in the combined analysis over years and locations (Table 13). The highest CP content was attained in *V. villosa* intercropping followed by *V. dasycarpa* intercropping and the lowest was in pure stand elephant grass. Table 14 indicates the ash content, which was comparable and significantly (P<0.05) lower in vetch *(V. dasycarpa and V. villosa)* intercropping than pure stand elephant grass at Holetta, Debre Zeit, in year 1 and in the combined analysis over years and locations. Moreover, in year 2, significantly (P<0.05) higher ash content was recorded in pure stand elephant grass followed by *V. villosa* intercropping, while the lowest was recorded in *V. dasycarpa* intercropping.

Table 13. Mean crude protein (CP) content (% in DM basis) of elephant grass forage during the establishment year (Year 1) and in the regrowth during the second year (Year 2) as affected by vetch intercropping and plant spacing (combined over years and locations)

Treatment	**Location**		**Year**		**Mean**
	Holetta	Debre Zeit	Year 1	Year 2	
Vetch Intercropping (I)					
Pure stand Elephant G	8.72^{b}	7.01^{b}	9.59^{b}	6.15^{c}	7.87^{b}
Elephant G + *V. dasycarpa*	15.64^{a}	12.17^{a}	19.87^{a}	7.94^{b}	13.91^{a}
Elephant G + *V. villosa*	15.36^{a}	12.83^{a}	19.31^{a}	8.38^{a}	14.09^{a}
P-value	0.0001	0.0001	0.0001	0.0001	0.001
Plant Spacing (S), cm					
S1 (75 x 75)	13.46	11.24	16.94	7.77	12.35
S2 (100 x 50)	12.96	10.91	16.29	7.57	11.93
S3 (125 x 125)	13.65	10.41	15.96	7.44	12.03
S4 (50 x 50)	12.90	10.13	15.84	7.18	11.51
Mean	13.24	10.67	16.26	7.49	11.96
SEM	0.212	0.174	0.174	0.095	0.139
CV (%)	24.40	18.86	13.42	8.71	23.19
I*S	NS	NS	NS	NS	NS
P-value	0.8696	0.3569	0.4410	0.0632	0.6417

$^{a\text{-}c}$ Means followed by different superscripts within a column are significantly different (P<0.05); Elephant G = elephant grass; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

Table 14. Mean ash content (% in DM basis) of elephant grass forage during the establishment year (Year 1) and in the regrowth during the second year (Year 2) as affected by vetch intercropping and plant spacing (combined over years and locations)

Treatment	**Location**		**Year**		**Mean**
	Holetta	Debre Zeit	Year 1	Year 2	
Vetch Intercropping (I)					
Pure stand Elephant G	19.26[a]	16.19[a]	17.36[a]	18.08[a]	17.72[a]
Elephant G + *V. dasycarpa*	14.79[b]	15.35[b]	13.46[b]	16.68[b]	15.07[b]
Elephant G + *V. villosa*	15.06[b]	14.90[b]	12.04[b]	17.37[ab]	14.98[b]
P-value	0.0001	0.0013	0.0001	0.0013	0.0001
Plant Spacing (S), cm					
S1 (75 x 75)	16.28	15.23	13.72	17.63	15.76
S2 (100 x 50)	16.08	15.18	13.78	17.31	15.63
S3 (125 x 125)	16.89	15.86	15.03	17.50	16.38
S4 (50 x 50)	16.23	15.64	14.63	17.08	15.94
Mean	16.37	15.48	14.29	17.38	15.92
SEM	0.180	0.128	0.172	0.132	0.117
CV (%)	14.22	7.58	14.85	7.20	12.38
I*S	NS	NS	NS	NS	NS
P-value	0.7391	0.2436	0.1865	0.5748	0.4006

[a-b] Means followed by different superscripts within a column are significantly different (P<0.05); Elephant G = elephant grass; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

The NDF content was comparable and significantly (P<0.05) lower in vetch *(V. dasycarpa and V. villosa)* intercropping than pure stand elephant grass at Holetta, Debre Zeit, in year 1, year 2 and in the combined analysis over years and locations (Table 15). The effect of vetch intercropping did not significantly (P>0.05) affect the ADF contents over years and locations (Table 16). Comparable and significantly (P<0.05) higher ADL (Table 17) and IVDMD (Table 18) contents were recorded in vetch *(V. dasycarpa and V. villosa)* intercropping with elephant grass than pure stand elephant grass at both locations and years in the combined analysis. The effecs of plant spacing, and interaction between vetch intercropping and plant spacing were not significant (P<0.05) on the chemical composition (ash, CP, NDF, ADF and ADL) parameters and *in vitro* dry matter digestibility (IVDMD), except plant spacing of elephant grass on the NDF content in year1; it was higher at narrower plantg spacing than wider spacing.

Table 15. Mean neutral detergent fiber (NDF) content (% in DM basis) of elephant grass forage during the establishment year (Year 1) and in the regrowth during the second year (Year 2) as affected by vetch intercropping and plant spacing (combined over years and locations)

Treatment	**Location**		**Year**		**Mean**
	Holetta	Debre Zeit	Year 1	Year 2	
Vetch Intercropping (I)					
Pure stand Elephant G	67.69^{a}	69.83^{a}	61.73^{a}	75.78^{a}	68.76^{a}
Elephant G + *V. dasycarpa*	60.74^{b}	65.56^{b}	52.70^{b}	73.60^{b}	63.14^{b}
Elephant G + *V. villosa*	60.70^{b}	64.43^{b}	50.64^{b}	74.49^{b}	62.56^{b}
P-value	0.0001	0.0001	0.0001	0.0011	0.0001
Plant Spacing (S), cm					
S1 (75 x 75)	61.29	65.77	52.65^{b}	74.42	63.53
S2 (100 x 50)	62.93	66.04	54.33^{ab}	74.65	64.49
S3 (125 x 25)	64.19	67.21	56.57^{a}	74.82	65.70
S4 (50 x 50)	63.76	67.39	56.55^{a}	74.60	65.58
Mean	63.04	66.60	55.02	74.62	64.82
SEM	0.256	0.212	0.234	0.164	0.176
CV (%)	7.51	4.84	7.15	2.60	6.90
I*S	NS	NS	NS	NS	NS
P-value	0.2791	0.3374	0.0093	0.9400	0.1392

$^{a-b}$ Means followed by different superscripts within a column are significantly different (P<0.05); Elephant G = elephant grass; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

Table 16. Mean acid detergent fiber (ADF) content (% in DM basis) of elephant grass forage during the establishment year (Year 1) and in the regrowth during the second year (Year 2) as affected by vetch intercropping and plant spacing (combined over years and locations)

Treatment	Loction		Year		Mean
	Holetta	Debre Zeit	Year 1	Year 2	
Vetch Intercropping (I)					
Pure stand Elephant G	45.16	45.35	38.75	51.76	45.25
Elephant G + *V. dasycarpa*	45.93	45.15	39.51	51.56	45.54
Elephant G + *V. villosa*	46.70	45.47	39.99	52.18	46.08
P-value	0.0862	0.8152	0.1576	0.5124	0.1625
Plant Spacing (S), cm					
S1 (75 x 75)	45.39	45.07	38.85	51.61	45.23
S2 (100 x 50)	46.50	45.09	39.54	52.05	45.79
S3 (125 x 25)	46.05	44.91	39.81	51.19	45.50
S4 (50 x 50)	45.77	46.17	39.47	52.48	45.97
Mean	45.93	45.32	39.41	51.83	45.62
SEM	0.181	0.156	0.176	0.161	0.122
CV (%)	5.14	3.85	5.63	3.62	4.73
I*S	NS	NS	NS	NS	NS
P-value	0.5540	0.1352	0.6163	0.2027	0.4808

Means followed by different superscripts within a column are significantly different ($P<0.05$); Elephant G = elephant grass; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

Table 17. Mean acid detergent lignin (ADL) content (% in DM basis) of elephant grass forage during the establishment year (Year 1) and in the regrowth during the second year (Year 2) as affected by vetch intercropping and plant spacing (combined over years and locations)

Treatment	**Loction**		**Year**		**Mean**
	Holetta	Debre Zeit	Year 1	Year 2	
Vetch Intercropping (I)					
Pure stand Elephant G	5.49^{b}	5.50^{b}	5.46^{b}	5.53^{b}	5.50^{b}
Elephant G + *V. dasycarpa*	9.22^{a}	9.43^{a}	9.56^{a}	9.08^{a}	9.32^{a}
Elephant G + *V. villosa*	9.60^{a}	9.38^{a}	9.65^{a}	9.32^{a}	9.49^{a}
P-value	0.0001	0.0001	0.0001	0.0001	0.0001
Plant Spacing (S), cm					
S1 (75 x 75)	7.90	8.00	8.31	7.59	7.95
S2 (100 x 50)	7.94	8.18	8.03	8.09	8.06
S3 (125 x 25)	8.05	8.10	8.07	8.08	8.08
S4 (50 x 50)	8.52	8.13	8.49	8.16	8.32
Mean	8.10	8.10	8.22	7.98	8.10
SEM	0.117	0.116	0.119	0.115	0.082
CV (%)	12.13	11.91	12.36	11.85	12.00
I*S	NS	NS	NS	NS	NS
P-value	0.2202	0.9559	0.4941	0.2659	0.4216

[a-b] Means followed by different superscripts within a column are significantly different ($P<0.05$); Elephant G = elephant grass; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

Table 18. Mean *in vitro* dry mater digestibility (IVDMD) (% in DM basis) of elephant grass forage during the establishment year (Year 1) and in the regrowth during the second year (Year 2) as affected by vetch intercropping and plant spacing (combined over years and locations)

Treatment	**Location**		**Year**		**Mean**
	Holetta	Debre Zeit	Year 1	Year 2	
Vetch Intercropping (I)					
Pure stand Elephant G	59.95^{b}	56.09^{b}	63.06^{b}	52.99^{b}	58.02^{b}
Elephant G + *V. dasycarpa*	62.69^{a}	62.14^{a}	69.69^{a}	54.97^{a}	62.41^{a}
Elephant G + *V. villosa*	63.15^{a}	62.00^{a}	70.13^{a}	54.90^{a}	62.58^{a}
P-value	0.0001	0.0001	0.0001	0.0159	0.0001
Plant Spacing (S), cm					
S1 (75 x 75)	62.15	59.94	67.81	54.18	61.05
S2 (100 x 50)	62.41	60.79	68.43	54.49	61.60
S3 (125 x 25)	61.37	59.16	66.47	54.06	60.27
S4 (50 x 50)	61.79	60.42	67.80	54.41	61.10
Mean	61.93	60.08	67.62	54.28	61.00
SEM	0.186	0.207	0.185	0.190	0.146
CV (%)	4.00	5.16	3.63	4.81	5.06
I*S	NS	NS	NS	NS	NS
P-value	0.6152	0.4366	0.1171	0.9579	0.3325

$^{a-b}$ Means followed by different superscripts within a column are significantly different (P<0.05); Elephant G = elephant grass; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

4.1.3. In sacco dry matter degradability and degradability characteristics of elephant grass-vetch mixed forages

4.1.3.1. In sacco dry matter degradability

The *in sacco* dry matter degradability (DMD) of elephant grass forage as affected by vetch intercropping is given in Table 19. Vetch intercropping (vetch intercropped with elephant grass) had affected ($P<0.05$) *in sacco* degradability of elephant grass forage incubated up to 96 hrs. Interaction effect of vetch intercropping and location has also affected ($P<0.05$) *in sacco* degradability when incubated at 6, 12 and 96 hours. At Holetta, comparable and significantly ($P<0.05$) higher DMD of elephant grass forage was measured in vetch intercropping plots than pure stand elephant grass from 6-48 hours of incubation, while at 72 and 96 hours significantly ($P<0.05$) the highest DMD was observed in *Vicia villosa* intercropping followed by *Vicia dasycarpa* intercropping and the lowest was recorded in pure stand elephant grass ($P<0.05$). At Debre Zeit, the DMD of forage was significantly ($P<0.05$) higher in vetch intercropping than pure stand grass at 6, 12, 72 and 96 hours of incubation, while significantly ($P<0.05$) the highest DMD was measured in *Vicia villosa* intercropping followed by *Vicia dasycarpa* intercropping and the lowest ($P<0.05$) was recorded in pure stand elephant grass at 48 and 72 hours of incubation. Generally, the trend of ruminal in *sacco* DMD was higher in vetch intercropping plots than pure stand elephant grass at all incubation hours at both locations. Furthermore, significantly ($P<0.05$) greater DMD was recorded at Holetta than at Debre Zeit, except at 6 hours of incubation.

Table 19. *In sacco* dry matter degradability (DMD) (on % dry matter basis) of elephant grass forage as influenced by vetch intercropping during the establishment year (Year 1) at Holetta and Debre Zeit (at a spacing of 50 cm x 50 cm between rows and plants)

Location	**Treatment (Vetch Intercropping)**	**Incubation time (h)**						
		0	6	12	24	48	72	96
Holetta	Pure stand Elephant G	14.00	26.82[b]	39.27[b]	50.95[b]	62.69[b]	67.44[b]	68.05[c]
	Elephant G + *V. dasycarpa*	21.72	38.03[a]	49.43[a]	57.49[a]	66.38[a]	68.93[ab]	71.31[b]
	Elephant G + *V. villosa*	19.45	38.05[a]	47.33[a]	57.92[a]	66.97[a]	71.34[a]	73.56[a]
	SEM	-	0.453	0.332	0.382	0.277	0.391	0.292
	P-value	-	0.0026	0.0005	0.0049	0.0031	0.0406	0.0024
Debre Zeit	Pure stand Elephant G	16.68	31.05[b]	39.46[b]	49.47[c]	59.73[c]	64.82[b]	65.89[b]
	Elephant G + *V. dasycarpa*	23.70	36.21[a]	44.46[a]	54.87[b]	62.49[b]	66.81[a]	67.70[a]
	Elephant G + *V. villosa*	20.96	35.23[a]	44.95[a]	55.43[a]	64.99[a]	66.71[a]	68.33[a]
	SEM	-	0.378	0.424	0.137	0.245	0.264	0.274
	P-value	-	0.0163	0.0253	0.0001	0.0007	0.0292	0.0252
Significance								
Location (L)		-	NS	**	**	***	***	***
Vetch Intercropping (I)		-	***	***	***	***	**	***
L* I		-	*	*	NS	NS	NS	*

[a-c] Means followed by different superscripts within a column are significantly different (P<0.05); Elephant G = elephant grass; SEM= standard error of the mean; *= (P<0.05); ** = (P<0.01) ; *** = (P<0.001); NS= non-significant

4.1.3.2. In sacco dry matter degradability characteristics

The *in sacco* DMD characteristics of elephant grass forage as affected by vetch intercropping is presented in Table 20. Significant (P<0.05) effect of vetch intercropping, and interaction between location and vetch intercropping were found on the *in sacco* DMD characteristics of elephant grass at Holetta and Debre Zeit, except the rate at which the ‘’b” fraction degraded (i.e., “c” fraction) at Holetta and the potential degradability (PD) at Debre Zeit. At Holetta, the highest (P<0.05) rapidly degradable ‘’a” fraction was observed in *Vicia dasycarpa* intercropping followed by *Vicia villosa* intercropping and the lowest was recorded in pure stand elephant grass. The highest ‘’a” fraction was recorded in *Vicia dasycarpa* intercropping followed by pure stand elephant grass and the lowest was observed in *Vicia villosa* intercropping at Debre Zeit (P<0.05). At Holetta, the highest (P<0.05) potentially, but slowly degradable ‘’b” fraction was obtained in pure stand elephant grass followed by *Vicia villosa* intercropping and the lowest was recorded in *Vicia dasycarpa* intercropping. The “b” fraction was comparable and lower (P<0.05) in pure stand elephant grass and *Vicia dasycarpa* intercropping than *Vicia dasycarpa* intercropping at Debre Zeit. Comparable and higher PD was observed in vetch intercropping than pure stand elephant grass at Holetta (P<0.05), while the PD was not significant (P>0.05) at Debre Zeit. Comparable and higher (P<0.05) effective degradability (ED) was recorded in vetch intercropping than pure stand elephant grass at both locations. The rate at which the ‘’b” fraction degraded (i.e., “c” fraction) was significant at Holetta (P<0.05), but not at Debre Zeit in vetch intercropping treatment.

Table 20. *In sacco* dry matter degradability (DMD) characteristics of elephant grass forage as influenced by vetch intercropping during the establishment year (Year 1) at Holetta and Debre Zeit

Treatment	**Holetta**					**Debre Zeit**				
(Vetch Intercropping)	a	b	PD	ED	c	a	b	PD	ED	c
	%				(/h)	%				(/h)
Pure stand Elephant G	13.92^{c}	54.73^{a}	68.65^{b}	47.64^{b}	0.048	21.14^{b}	45.73^{b}	66.87	47.47^{b}	0.041^{c}
Elephant G + *V. dasycarpa*	22.54^{a}	47.53^{c}	70.07^{ab}	54.61^{a}	0.063	24.13^{a}	43.37^{b}	67.50	51.54^{a}	0.052^{b}
Elephant G + *V. villosa*	20.84^{b}	51.16^{b}	72.00^{a}	54.61^{a}	0.058	17.56^{c}	49.77^{a}	67.33	51.64^{a}	0.065^{a}
SEM	0.287	0.311	0.345	0.277	0.0237	0.200	0.387	0.358	0.225	0.0224
P-value	0.0003	0.0014	0.0456	0.0004	0.0559	0.0001	0.0108	0.7961	0.0006	0.0071

Significance					
Source of variation	a	b	PD	ED	c
Location (L)	***	***	***	***	NS
Vetch Intercropping (I)	***	***	NS	***	***
L* I	***	***	NS	*	*

$^{a-c}$ Means followed by different superscripts within a column are significantly different (P<0.05); Elephant G = elephant grass; a= rapidly degradable fraction; b= potentially, but slowely degradable fraction, PD= potential degradability, ED= effective degradability, c= passage rate (the rate at which the ''b" fraction degraded) **;** SEM= standard error of the mean; *= (P<0.05); **= (P<0.01) ; *** = (P<0.001); NS= non-significant

4.2. Experiment 2- Harvesting Height of Elephant Grass and Nitrogen-Fertilizer Rates

4.2.1. Forage agronomic performances

4.2.1.1. Survival rate

Results of analysed data on survival rate percentage of elephant grass at three harvesting heights: HH1, HH2 and HH 3 and four nitrogen fertilizer rates: N1, N2, N3 and N4 are presented in Table 21. Comparable and significantly ($P < 0.05$) lower survival rate of elephant grass was recorded at HH1 and HH3 than HH2 at Holetta, Debre Zeit, in year 1 and in the combined analysis over years and locations, whereas the effect of harvesting heights was not significant on the survival rate of elephant grass in year 2 ($P > 0.05$). Generally, the trend of survival rate has increased from HH1 to HH2 and decreased from HH2 to HH3. Nitrogen fertilizer (N) application during the establishement year and in the regrowth of the second year at different rates significantly ($P < 0.05$) affected the stand count of elephant grass which is an indication of survival rate percentage. The highest survival rate was observed in N4 treatment of N leveles followed by N3, N2 and the lowest was recorded in N1 plots or treatments at Holetta, Debre Zeit, in year 1, year 2 and over years and locations. With the exception of Holetta, the effect of interaction between harvesting height and nitrogen fertilizer on the survival rate percentage of elephant grass forage was not significant ($P > 0.05$) over years and locations.

Table 21. Mean survival rate of elephant grass during the establishment year and in the regrowth during the second year (% survived from the initial number of root splits planted) as affected by harvesting height (cm) and nitrogen fertilizer (kg/ha) (combined over years and locations)

Treatment	**Location**		**Year**		**Mean**
	Holetta	Debre Zeit	Year 1	Year 2	
Harvesting Height					
HH1 (50)	75.5^{ab}	53.1^{b}	65.1^{b}	63.5	64.3^{b}
HH2 (100)	76.6^{a}	61.7^{a}	72.2^{a}	66.1	69.1^{a}
HH3 (150)	74.6^{b}	54.5^{b}	65.8^{b}	63.3	64.5^{b}
P-value	0.0125	0.0051	0.0027	0.3396	0.0014
Nitrogen Fertilizer					
N1 (0)	70.7^{d}	51.7^{b}	62.6^{c}	59.9^{b}	61.2^{c}
N2 (50)	73.7^{c}	56.5^{ab}	66.4^{bc}	63.8^{b}	65.1^{b}
N3 (100)	76.5^{b}	56.2^{ab}	68.6^{ab}	64.1^{b}	66.4^{b}
N4 (150)	81.3^{a}	61.4^{a}	73.3^{a}	69.4^{a}	71.4^{a}
Mean	75.6	56.4	67.7	64.3	66.0
SEM	0.18	0.36	0.32	0.32	0.22
CV (%)	3.05	16.53	11.10	11.23	10.83
HH*N	0.0001	NS	NS	NS	NS
P-value	0.0001	0.0291	0.0009	0.0027	0.0001

$^{a-d}$ Means followed by different superscripts within a column are significantly different (P<0.05); HH = harvesting height; N= nitrogen fertilizer; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

4.2.1.2. Tillering Performance

Table 22 shows data analysis result on the number of tillers per plant (NTPP) of elephant grass as affected by harvesting height (HH) and application of nitrogen fertilizer (N) rate. Harvesting height of elephant grass has significantly ($P<0.05$) affected the NTPP of elephant grass. Higher NTPP of elephant grass was recorded at HH1 than at HH3, with the intermidate value at HH2 berween the two at Holetta, Debre Zeit, in year 1, year 2 and in the combined effect over years and locations. Application of different fertilizer rates resulted in significant ($P<0.05$) effects on tillering performanc. The highest ($P<0.05$) NTPP of elephant grass was recorded for N application rates of N3 and N4 followed by N2 and the lowest was recorded for N1 at Holetta, Debre Zeit, in year 1, year 2 and in the combined effect over years and locations. Generally, the number of tillers per plant of elephant grass increased with an increase in application rates of nitrogen fertilizer: N1 < N2 < N3 < N4.

4.2.1.3. Leaf to stem ratio

The leaf to stem ratio (LSR) of elephant grass at three harvesting heights (HH) and nitrogen fertilizer (N) rates is presented in Table 23. Significantly ($P<0.05$) the highest LSR of elephant geass was recorded at HH1 and the lowest was obtained at HH3 , with HH2 having intermidate value berween the two at Holetta, Debre Zeit, in year 2 and in the combined analysis over years and locations. In year 1, comparable and significantly ($P> 0.05$) lower LSR was recorded at HH2 and HH3 than HH1. There was a decreasing trend in the LSR of elephant grass with an increase in the harvesting height: HH1 > HH2 > HH3. Comparable and significantly ($P<0.05$) higher LSR was recorded in N rate treatments of N3 and N4 than N1 and N2 at Holetta, Debre Zeit, in year 2 and in the combined analysis over years and locations. In general, the trend of elephant grass LSR increased with an increase in nitrogen fertilizer application rates: N1 < N2 < N3 < N4. The effect of interaction between harvesting height and nitrogen fertilizer was not significant on the LSR of elephant grass ($P>0.05$).

Table 22. Mean number of tillers per plant of elephant grass stand during the establishment year (Year 1) and in the regrowth during the second year (Year 2) as affected by harvesting height (cm) and nitrogen fertilizer (kg/ha) (combined over years and locations)

Treatment	**Location**		**Year**		**Mean**
	Holetta	Debre Zeit	Year 1	Year 2	
Harvesting Height (HH)					
HH1 (50)	44.3[a]	48.7[a]	24.6[a]	68.4[a]	46.5[a]
HH2 (100)	41.5[b]	43.3[b]	23.9[a]	60.9[b]	42.4[b]
HH3 (150)	40.6[b]	38.6[c]	20.8[b]	58.4[b]	39.6[c]
P-value	0.0128	0.0001	0.0001	0.0001	0.0001
Nitrogen Fertilizer (N)					
N1 (0)	37.4[c]	37.2[c]	19.4[c]	55.2[c]	37.3[c]
N2 (50)	41.6[b]	42.5[b]	23.1[b]	61.0[b]	42. 0[b]
N3 (100)	44.7[a]	46.3[a]	24.8[ab]	66.2[a]	45.5[a]
N4 (150)	44.8[a]	48.2[a]	25.1[a]	67.9[a]	46.5[a]
Mean	42.1	43.5	23.1	62.6	42.8
SEM	0.25	0.28	0.20	0.29	0.20
CV (%)	10.39	13.05	12.76	9.71	12.80
HH*N	NS	NS	NS	NS	NS
P-value	0.0001	0.0001	0.0001	0.0001	0.0001

[a-c] Means followed by different superscripts within a column are significantly different ($P<0.05$); SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

Table 23. Mean leaf to stem ratio of elephant grass at forage harvesting stage during the establishment year and in the regrowth during the second year as affected by different harvesting height (cm) and nitrogen fertilizer (kg/ha) (combined over years and locations)

Treatment	**Location**		**Year**		**Mean**
	Holetta	D/ Zeit	Year 1	Year 2	
Harvesting Height (HH)					
HH1 (50)	2.44[a]	2.81[a]	2.93[a]	2.33[a]	2.62[a]
HH2 (100)	1.62[b]	2.29[b]	2.01[b]	1.91[b]	1.96[b]
HH3 (150)	1.39[c]	1.87[c]	1.78[b]	1.45[c]	1.62[c]
P-value	0.0001	0.0001	0.0001	0.0001	0.0001
Nitrogen Fertilizer (N)					
N1 (0)	1.54[b]	1.95[b]	1.99	1.49[b]	1.74[b]
N2 (50)	1.56[b]	2.24[ab]	2.10	1.70[b]	1.90[b]
N3 (100)	2.12[a]	2.55[a]	2.41	2.20[a]	2.33[a]
N4 (150)	2.06[a]	2.56[a]	2.45	2.19[a]	2.32[a]
Mean	1.82	2.32	2.24	1.89	2.07
SEM	0.068	0.094	0.094	0.070	0.061
CV (%)	18.22	27.40	28.33	18.79	26.10
HH*N	NS	NS	NS	NS	NS
P-value	0.0001	0.0166	0.0965	0.0001	0.0001

[a-c] Means followed by different superscripts within a column are significantly different (P<0.05); SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

4.2.1.4. Average annual forage dry matter and crude protein yields

Mean annual yields of forage dry matter and crude protein of elephant grass as influenced by harvesting heights and nitrogen fertilizer application rates are presented in Table 24. The yields of DM and CP were significantly ($P < 0.05$) affected by different harvesting heights (HH) and nitrogen fertilizer (N) application rates. However, the interaction effect between harvesting height and nitrogen fertilizer was not significant

($P < 0.05$) on the DM and CP yields at Holetta and at Debre Zeit, and over these locations.

At Holetta, comparable and significantly ($P < 0.05$) higher elephant grass DM yields were obtained at HH2 and HH3 than HH1. Significantly ($P < 0.05$) the highest DMY values were recorded at HH3 followed by HH2 and the lowest was obtained at HH1 at Debre Zeit and the combined analysis over locations. At Holetta and over locations, comparable and significantly ($P < 0.05$) the highest DMY were recorded in N3 and N4 followed by N2 and the lowest values were observed in N1 application rates. The overall mean dry matter yield values of elephant grass (5.41 t/ha, 11.87 t/ha) over years at Holetta and Debre Zeit, respectively were recorded. Generally, the trend of elephant grass DMY increased with an increase in harvesting height and nitrogen fertilizer application rate: HH1 < HH2 < HH3 and N1< N2 < N3 < N4, respectively.

Significantly ($P < 0.05$) higher elephant grass forage CP yields were recorded at HH2 and HH3 than HH1 at Holetta and combined effect over locations. At Debre Zeit, significantly ($P < 0.05$) higher CP yield was obtained at HH3 followed by HH2 while the lowest value was recoreded at HH1. On the other hand, significantly ($P<0.05$) higher forage CP yields of elephant grass were recorded for N rates: N3 and N4 followed by N2 while the lowest value was recorded for N1 at Holetta and over locations. Contrary to what was recorded at Holeta, at Debre Zeit, comparable and significantly ($P < 0.05$) higher CP yields were recorded for N rates of N4, N3 and N2 than N1. The overall mean CPY values (averaged over HH and N) (0.50 t/ ha, 1.00 t/ ha) were recorded at Holetta and at Debre Zeit, respectively. The trend of elephant grass CPY was also more or less increased with an increase in harvesting heights and nitrogen fertilizer rates.

Table 24. Forage dry matter and crude protein yields (t/ha) of elephant grass forage during the establishment year (Year 1) and in the regrowth of the second year (Year 2) as influenced by harvesting height (cm) and nitrogen fertilizer (kg/ha) at Holetta and Debre Zeit and over locations

Treatment	**Holetta**			**Debre Zeit**			**Overall Mean**	**Crude protein Yield (t/ha)**		**Overall Mean**
	Year 1	Year 2	Mean	Year 1	Year 2	Mean		Holetta	Debre Zeit	
Harvesting Height										
HH1 (50)	0.32	7.55^{b}	3.93^{b}	3.57^{b}	13.62^{c}	8.60^{c}	6.27^{c}	0.39^{b}	0.73^{c}	0.56^{b}
HH2 (100)	0.35	12.12^{a}	6.24^{a}	5.77^{a}	18.73^{b}	12.25^{b}	9.24^{b}	0.57^{a}	1.05^{b}	0.81^{a}
HH3 (150)	0.33	11.78^{a}	6.05^{a}	6.09^{a}	23.42^{a}	14.75^{a}	10.40^{a}	0.54^{a}	1.22^{a}	0.88^{a}
P-value	0.3907	0.0001	0.0001	0.0002	0.0001	0.0001	0.0001	0.0002	0.0001	0.0001
Nitrogen Fertilizer										
N1 (0)	0.30	8.66^{b}	4.48^{b}	3.47^{b}	14.53^{b}	9.00^{b}	6.74^{c}	0.39^{c}	0.73^{b}	0.56^{c}
N2 (50)	0.33	9.93^{b}	5.13^{ab}	5.22^{a}	18.05^{a}	11.64^{a}	8.38^{b}	0.47^{bc}	0.99^{a}	0.73^{b}
N3 (100)	0.36	11.67^{a}	6.02^{a}	5.94^{a}	21.00^{a}	13.47^{a}	9.74^{a}	0.57^{a}	1.15^{a}	0.86^{a}
N4 (150)	0.33	11.67^{a}	6.00^{a}	5.95^{a}	20.76^{a}	13.35^{a}	9.68^{ab}	0.56^{ab}	1.13^{a}	0.84^{ab}
Mean	0.33	10.48	5.41	5.14	18.59	11.87	8.64	0.50	1.00	0.75
SEM	0.043	0.224	0.16	0.178	0.316	0.25	0.17	0.118	0.073	0.046
CV (%)	20.60	17.22	17.33	22.30	19.36	19.32	23.16	18.85	19.11	22.62
HH*N	NS	0.0001	NS	0.0001	0.0002	NS	NS	NS	NS	NS
P-value	0.3515	0.0029	0.0050	0.0001	0.0021	0.0013	0.0001	0.0016	0.0003	0.0001

$^{a-c}$ Means followed by different superscripts within a column are significantly different ($P<0.05$); HH = harvesting height; N= nitrogen fertilizer; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

4.2.2. Forage chemical composition and in vitro dry matter digestibility

Elephant grass forage chemical composition (ash, CP, NDF, ADF, ADL contents) and *in vitro* dry matter digestibility (IVDMD) at three harvesting heights and four nitrogen fertilizer rates on the regrowths of the second year are presented in Tables 25, 26 and 27. The interaction effect between harvesting heights and nitrogen fertilizer rates was not significant (P>0.05) on the ash, CP, NDF, ADL contents and IVDMD except the ash content at Debre Zeit and the ADF content over the combined effect of locations.

Table 25 shows the different harvesting heights of elephant grass did not significantly (P>0.05) affect the ash contents at Debre Zeit and the combined effect over locations. However, comparable and significantly (P<0.05) higher ash content was recorded at HH1 and HH2 than at HH3 at Holetta. Significantly (P<0.05) higher CP content was obtained at HH1 than at HH3, with intermediate value was recorded at HH2 at Holetta, while at Debre Zeit, comparable and significantly (P<0.05) higher CP content was recorded at HH1 and HH2 than at HH3 (Table 26). In the combined analysis over locations, significantly (P<0.05) the highest CP content was recorded at HH1 followed by HH2, while the lowest was obtained at HH3. The NDF content was comparable and significantly (P<0.05) higher at HH2 and HH3 than at HH1 at both locations (Table 26).

The application of different nitrogen fertilizer rates did not significantly (P>0.05) affect the ash contents of elephant grass. The CP content was comparable and significantly (P<0.05) higher in treatment N2, N3 and N4 than in N1 at Debre Zeit and in the combined effect over locations, but it was not significant at Holetta (P>0.05). The NDF content was significantly (P<0.05) higher in N1 than in N2, N3 and N4 at Holetta. In the combined analysis over locations, the NDF content was comparable and significantly (P<0.05) higher in N1 and N2 than in N3 and N4, while at Debre Zeit the NDF content was not significant (P>0.05).

Table 25. Ash contents of elephant grass forage as affected by harvesting height (cm) and nitrogen fertilizer (kg/ha) during year 2 (regrowths in the second year of establishment) at Holetta and Debre Zeit

Treatment	**Ash (% DM basis)**		
	Holetta	Debre Zeit	Mean
Harvesting Height (HH)			
HH1 (50)	18.30[a]	17.21	17.76
HH2 (100)	18.14[a]	17.39	17.77
HH3 (150)	17.75[b]	17.46	17.60
P-value	0.0054	0.0953	0.2398
Nitrogen Fertilizer (N)			
N1 (0)	18.23	17.33	17.78
N2 (50)	18.18	17.31	17.74
N3 (100)	17.94	17.51	17.73
N4 (150)	17.91	17.24	17.58
Mean	18.07	17.35	17.71
SEM	0.102	0.085	0.068
CV (%)	2.09	1.51	2.14
HH*N	NS	0.0187	NS
P-value	0.2067	0.1914	0.4052

[a-b] Means followed by different superscripts within a column are significantly different ($P<0.05$); SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

Table 26. Crude protein (CP) and Neutral detergent fibre (NDF) of elephant grass forage as affected by harvesting height (cm) and nitrogen fertilizer (kg/ha) during year 2 (regrowths in the second year of establishment) at Holetta and Debre Zeit

Treatment	**CP (% DM basis)**			**NDF (% DM basis)**		
	Holetta	D/Zeit	Mean	Holetta	D/Zeit	Mean
Harvesting Height						
HH1 (50)	9.72^{a}	8.58^{a}	9.15^{a}	64.24^{b}	62.79^{b}	63.52^{b}
HH2 (100)	9.16^{b}	8.57^{a}	8.86^{b}	64.81^{a}	63.64^{a}	64.22^{a}
HH3 (150)	8.87^{b}	8.27^{b}	8.57^{c}	65.02^{a}	63.74^{a}	64.38^{a}
P-value	0.0076	0.0129	0.0004	0.0137	0.0050	0.0001
Nitrogen Fertilizer						
N1 (0)	8.78	8.06^{b}	8.42^{b}	65.24^{a}	63.63	64.43^{a}
N2 (50)	9.22	8.61^{a}	8.92^{a}	64.64^{b}	63.80	64.22^{a}
N3 (100)	9.53	8.62^{a}	9.08^{a}	64.50^{b}	63.01	63.76^{b}
N4 (150)	9.45	8.60^{a}	9.03^{a}	64.39^{b}	63.12	63.75^{b}
Mean	9.25	8.47	8.86	64.69	63.39	64.04
SEM	0.130	0.086	0.080	0.130	0.138	0.095
CV (%)	6.53	3.11	5.31	0.94	1.09	1.04
HH*N	NS	NS	NS	NS	NS	NS
P-value	0.0614	0.0003	0.0003	0.0339	0.0654	0.0054

[a-c] Means followed by different superscripts within a column are significantly different (P<0.05); D/Zeit= Debre Zeit HH = harvesting height; N= nitrogen fertilizer; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

The ADF and ADL contents were lower at HH1 (P<0.05) than the other harvesting heights exhibiting comparable and significantly (P<0.05) higher values (for HH2 and HH3) for both fractions (ADF and ADL) at Debre Zeit and the combined effect over locations with the exception of the ADL content at Holetta (Table 27). Significantly (P<0.05) the highest IVDMD value was obtained at HH1 followed by HH2, while the lowest was recorded at HH3 at Holetta and the combined effect over locations, whereas at Debre Zeit comparable and significantly (P<0.05) higher IVDMD of elephant grass forage was recorded at HH1 and HH2 than at HH3 (Table 27).

The ADF content of elephant grass forage was comparable and significantly (P<0.05) higher in treatment N1 and N2 than in N4, with N3 having the intermediate value between the two at Holetta. Comparable and significantly (P<0.05) the highest ADF content was obtained in N1 and N2 followed by N4, while the lowest value was recorded in N3 at Debre Zeit. In the combined analysis over locations, significantly (P<0.05) the highest ADF content was recorded in N1 followed by N2, N4 and the lowest was obtained in N3. Comparable and significantly (P<0.05) the highest IVDMD of elephant grass was observed in treatment N3 and N4 and the lowest value was recorded in N1, with N2 having the intermediate value between the two at Debre Zeit and the combined effect over locations, while it was not significant (P>0.05) at Holetta.

Table 27. Acid detergent fibre (ADF), Acid detergent lignin (ADL) and *in vitro* dry matter digestibility (IVDMD) of elephant grass forage as affected by harvesting height (cm) and nitrogen fertilizer (kg/ha) during year 2 (regrowths in the second year of establishment) at Holetta and Debre Zeit

Treatment	**ADF (% DM basis)**			**ADL (% DM basis)**			**IVDMD (% DM basis)**		
	Holetta	Debre Zeit	Mean	Holetta	Debre Zeit	Mean	Holetta	Debre Zeit	Mean
Harvesting Height									
HH1 (50)	40.25[b]	40.85[b]	40.55[b]	5.51	5.52[b]	5.52[b]	70.41[a]	66.95[a]	68.68[a]
HH2 (100)	41.01[a]	41.14[ab]	41.07[a]	5.51	5.56[a]	5.53[a]	69.31[b]	66.58[a]	67.94[b]
HH3 (150)	40.46[ab]	41.43[a]	40.95[a]	5.52	5.56[a]	5.54[a]	67.48[c]	65.91[b]	66.69[c]
P-value	0.0032	0.0229	0.0066	0.1714	0.0135	0.0067	0.0001	0.0014	0.0001
Nitrogen Fertilizer									
N1 (0)	40.96[a]	41.42[a]	41.19[a]	5.51	5.54	5.52	68.47	66.00[b]	67.23[b]
N2 (50)	40.65[a]	41.29[a]	40.97[ab]	5.51	5.55	5.53	69.12	66.26[ab]	67.69[ab]
N3 (100)	40.54[ab]	40.69[b]	40.62[c]	5.51	5.55	5.53	69.38	66.83[a]	68.11[a]
N4 (150)	40.16[b]	41.15[ab]	40.65[bc]	5.51	5.55	5.53	69.29	66.81[a]	68.05[a]
Mean	40.58	41.14	40.86	5.51	5.55	5.53	69.06	66.48	67.77
SEM	0.117	0.115	0.082	0.017	0.030	0.018	0.155	0.130	0.102
CV (%)	1.21	1.16	1.40	0.19	0.60	0.44	1.24	0.92	1.27
HH*N	NS	NS	0.0136	NS	NS	NS	NS	NS	NS
P-value	0.0189	0.0223	0.0108	0.4231	0.7448	0.4888	0.1333	0.0183	0.0127

[a-c] Means followed by different superscripts within a column are significantly different (P<0.05); HH = harvesting height; N= nitrogen fertilizer; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

4.2.3. Dry matter degradability and degradability characteristics of elephant grass

4.2.3.1. In sacco dry matter degradability

Mean values of *in sacco* dry matter degradability (DMD) of elephant grass at three harvesting heights (HH) is presented in Table 28. Significant ($P<0.05$) effect of HH was found on the DMD of elephant grass at all incubation periods (6-96) at Holetta and Debre Zeit. The interaction (L* HH) effect of location and harvesting height on rumenal *in sacco* DMD was significantly ($P< 0.05$) different at 6 and 12 hours of incubation. At Holetta, significantly ($P<0.05$) higher DMD was measured at HH1 than HH2 and HH3 at 6 and 12 hours of incubation, but at 24, 48, 72 and 96 hours of incubation, significantly ($P<0.05$) the highest DM degradability was recorded in HH1 followed by HH2 , while the lowest value was recorded in HH3. At Debre Zeit, the highest ($P<0.05$) DMD was recorded at HH1 at 6, 72 and 96 hours of incubation followed by HH2 and the lowest ($P<0.05$) was measured in HH3. However, comparable and significantly ($P<0.05$) higher DMD was obtained at HH1 and HH2 than HH3 at 12, 24 and 48 hours of incubation. Except at 6 hours of incubation at HH2, significantly ($P<0.05$) higher DMD was recorded at Holetta than at Debre Zeit. At the early phase (≤ 48 hours of incubation), rates of DM degradability in all treatments were higher and afterwards the rate declined. The trend of elephant grass DM degradability at any given incubation hour increased in the order of harvesting height (HH1 > HH2 > HH3).

Table 28. *In sacco* dry matter degradability (DMD) (% in DM basis) parameters of elephant grass forage as influenced by harvesting height (cm) during year 2 (regrowths in the second year of establishment) at Holetta and Debre Zeit with the application of 100 kg N /ha/year

Location	**Treatment**	**Incubation time (h)**						
		0	6	12	24	48	72	96
	HH1 (50)	21.24	31.47[a]	40.77[a]	55.74[a]	69.81[a]	72.46[a]	72.98[a]
	HH2 (100)	18.96	25.03[b]	38.00[b]	50.83[b]	65.89[b]	69.96[b]	70.44[b]
Holetta	HH3 (150)	18.53	24.48[b]	37.26[b]	47.21[c]	62.70[c]	66.46[c]	68.16[c]
	SEM	-	0.295	0.273	0.389	0.287	0.258	0.307
	P-value	-	0.0007	0.0064	0.0040	0.0008	0.0007	0.0058
	HH1 (50)	20.36	29.59[a]	35.52[a]	48.03[a]	65.77[a]	70.99[a]	71.73[a]
	HH2 (100)	19.93	26.45[b]	34.43[a]	46.63[a]	63.38[a]	68.15[b]	68.80[b]
Debre Zeit	HH3 (150)	16.01	22.94[c]	29.59[b]	42.78[b]	58.55[b]	65.15[c]	65.26[c]
	SEM	-	0.306	0.328	0.364	0.441	0.345	0.364
	P-value	-	0.0017	0.0035	0.0129	0.0173	0.0068	0.0068
Significance								
Location (L)		-	NS	***	***	***	**	**
Harvesting Height (HH)		-	***	***	***	***	***	***
L*HH		-	*	**	NS	NS	NS	NS

[a-c] Means followed by different superscripts within a column are significantly different (P<0.05); HH= harvesting height;

SEM=standard error of the mean; CV= coefficient of variation; *= (P<0.05); ** = (P<0.01); *** = (P<0.001); NS= non-significant

4.2.3.2. In sacco dry matter degradability characteristics

The *in sacco* rumen dry matter degradability (DMD) characteristics of elephant grass at three harvesting heights is presented in Table 29. Significant ($P<0.05$) effect of harvesting height (HH) was found on the DMD characteristics of elephant grass at Holetta and Debre Zeit (except the potentially, but slowly degradable fraction “b” and the potential degradability (PD) fraction at Debre Zeit). The interaction effect of location by harvesting height was significant ($P<0.05$) on the rapidly degradable fraction “a” and ($P<0.05$) the effective degradability fraction (ED). At Hoetta, comparable and significantly ($P<0.05$) lower ‘’a” fraction was observed at HH2 and HH3 than HH1. The ‘’a” fraction was comparable and significantly ($P<0.05$) higher at *HH1* and HH2 than HH3 at Debre Zeit. At Holetta, comparable and significantly ($P<0.05$) higher ‘’b” fraction was recorded at HH1 and HH2 than HH3. However, the “b” fraction was not significantly different at Debre Zeit ($P>0.05$). Comparable and significantly ($P<0.05$) higher PD of elephant grass was recorded at HH1 and HH2 than at HH3 at Holetta and at Debre Zeit. The highest ($P<0.05$) ED fraction of elephant grass was recorded at HH1 followed by HH2 and the lowest was obtained at HH3 at both locations. At Holetta, the “c” fraction was not significant ($P<0.05$), but numerically higher at HH1, intermediate at HH2 and lower at HH3. Higher “c” fraction was recorded at HH1 and HH2 than at HH3, while it was not significant at Debre Zeit ($P>0.05$).

Table 29. *In sacco* dry matter degradability (DMD) (% in DM basis) characterstics of elephant grass forage as influenced by harvesting height (cm) during year 2 (regrowths in the second year of establishment) at Holetta and Debre Zeit

Treatment	**Holetta**					**Debre Zeit**				
	A	b	PD	ED	c	a	b	PD	ED	c
		%			(/h)	%				(/h)
HH1 (50)	20.09^{a}	55.02^{ab}	75.11^{a}	52.33^{a}	0.042	19.59^{a}	56.85	76.44^{a}	48.32^{a}	0.031
HH2 (100)	17.02^{b}	56.40^{a}	73.26^{a}	48.42^{b}	0.038	18.69^{a}	56.37	73.13^{ab}	46.49^{b}	0.031
HH3 (150)	16.86^{b}	53.56^{b}	70.58^{b}	46.24^{c}	0.036	14.63^{b}	54.43	71.00^{b}	42.35^{c}	0.029
SEM	0.203	0.293	0.311	0.235	0.0158	0.236	0.448	0.433	0.190	0.0128
P-value	0.0007	0.0272	0.0079	0.0003	0.0586	0.0006	0.3253	0.0408	0.0001	0.2566
					Significance					
Location (L)			NS	NS	NS			***		***
Harvesting Height (HH)			***	NS	***			***		*
L*HH			***	NS	NS			**		NS

[a-c] Means followed by different superscripts within a column are significantly different (P<0.05); a= rapidly degradable fraction; b= potentially, but slowely degradable fraction, PD=potential degradability; ED= effective degradability; c=passage rate (rate of degradation of b ; SEM= standard error of the mean; *= (P<0.05); ** = (P<0.01); *** = (P<0.001); NS= non-significant

4.3. Experiment 3- Fertilizer Rate and Plant Spacing of Elephant Grass

4.3.1. Forage agronomic performances

4.3.1.1. Survival rate

Table 30 shows the effects of nitrogen fertilizer application rate (N) and plant spacing (S) on the survival rate percentage of elephant grass. The survival rate of elephant grass was comparable and significantly ($P < 0.05$) higher in treatment N3 and N4 than in N1 and N2 at Holetta and in the combined analysis over years and locations. The survival rate of elephant grass was significantly ($P<0.05$) higher in treatment N4 than in N1 and N2, with N3 having intermediate value between these two in year 1, while at Debre Zeit and in year 2, the survival rate of elephant grass was not significantly ($P>0.05$) affected by application of nitrogen fertilizer rates.

The survival rate of elephant grass was comparable and significantly ($P < 0.05$) higher in plant spacing treatment S1 and S2 than in S3 and S4 at Holetta, Debre Zeit, in year 2 and in the combined analysis over years and locations. In year 1, comparable and significantly ($P<0.05$) higher survival rate was recorded in S1 and S2 than in S4, with S3 having the intermediate value between the two. The survival rate of elephant grass decreased with a decrease in plant spacing (an increase plant population density): S1>S2 >S3 >S4 treatments. The interaction effect of nitrogen fertilizer rate and plant spacing was significant ($P < 0.05$) on the survival rate of elephant grass forage over years and locations.

Table 30. Mean survival rate percentage (% survived from the initial number of root splits planted) of elephant grass forage during the establishment year and in the regrowth of the second year as affected by nitrogen fertilizer (kg/ha) and plant spacing (cm) (combined over years and locations)

Treatment	Holetta	Debre Zeit	Year 1	Year 2	Mean
Nitrogen Fertilizer (N)					
N1 (0)	71.8^{b}	51.7	63.5^{b}	60.0	61.8^{b}
N2 (50)	72.1^{b}	51.5	63.3^{b}	60.5	61.9^{b}
N3 (100)	77.2^{a}	54.8	67.8^{ab}	64.2	66.0^{a}
N4 (150)	80.5^{a}	57.3	72.3^{a}	65.5	68.9^{a}
P-value	0.0004	0.0534	0.0010	0.0821	0.0001
Plant Spacing (S)					
S1 (75 x 75)	79.2^{a}	55.6^{ab}	69.5^{a}	65.3^{ab}	67.4^{a}
S2 (100 x 50)	77.8^{a}	57.0^{a}	69.0^{a}	65.8^{a}	67.4^{a}
S3 (125 x 25)	72.6^{b}	51.4^{b}	65.6^{ab}	58.5^{c}	62.0^{b}
S4 (50 x 50)	72.0^{b}	51.3^{b}	62.8^{b}	60.6^{bc}	61.7^{b}
Mean	75.4	53.8	66.7	62.5	64.6
SEM	0.29	0.29	0.30	0.30	0.21
CV (%)	10.47	15.25	12.79	13.94	12.91
N*S	0.0001	0.0008	0.0030	0.0241	0.0001
P-value	0.0029	0.0372	0.0262	0.0106	0.0002

$^{a\text{-}c}$ Means followed by different superscripts within a column are significantly different ($P<0.05$); SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

4.3.1.2. Tillering performance

The effect of nitrogen fertilizer application rate (N) and plant spacing (S) of elephant grass forage on the number of tillers per plant (NTPP) of elephant grass is given in Table 31. The NTPP of elephant grass was significantly ($P < 0.05$) affected by N and S. Comparable and significantly ($P<0.05$) the highest NTPP was obtained in N3 and N4 followed by N2, while the lowest value was recorded in N1 at Holetta, in year 1 and over years and locations. At Debre Zeit and in year 2, comparable and significantly ($P<0.05$) higher NTPP was recorded in N3 and N4 than N1, with the value of N2 falling between the two. Generally, the trend of NTPP of elephant grass increased with an increase in the rate of nitrogen fertilizer (N1< N2< N3< N4). Comparable and significantly ($P<0.05$) higher NTPP of elephant grass were recorded in treatment S1 and S2 than in S3 and S4 at Holetta and in year 1. At Debre Zeit, in year 2 and the combined analysis over years and locations, significantly ($P<0.05$) higher NTPP was recorded in S1, S2 and S3 than S4. The trend of NTPP of elephant grass increased with an increase in plant spacing (S4 < S3 < S2 < S1). However, the interaction effect of nitrogen fertilizer and plant spacing was not significant ($P>0.05$) on the number of tillers per plant of elephant grass.

Table 31. Mean number of tillers per plant (NTPP) of elephant grass during the establishment year and in the regrowth of the second year as affected by nitrogen fertilizer (kg/ha) and plant spacing (cm) (combined over years and locations)

Treatment	Holetta	Debre Zeit	Year 1	Year 2	Mean
Nitrogen fertilizer (N)					
N1 (0)	37.6^{c}	40.9^{b}	25.7^{c}	52.9^{b}	39.3^{c}
N2 (50)	41.1^{b}	43.1^{ab}	27.7^{bc}	56.4^{ab}	42.1^{b}
N3 (100)	44.5^{a}	46.0^{a}	30.5^{a}	60.1^{a}	45.3^{a}
N4 (150)	43.7^{ab}	45.8^{a}	29.3^{ab}	60.2^{a}	44.7^{a}
P-value	0.0001	0.0401	0.0003	0.0016	0.0001
Plant spacing (S)					
S1 (75 x 75)	44.8^{a}	45.6^{a}	29.9^{a}	60.5^{a}	45.2^{a}
S2 (100 x 50)	43.0^{a}	46.8^{a}	29.8^{a}	60.0^{a}	44.9^{a}
S3 (125 x 25)	40.2^{b}	45.4^{a}	26.8^{b}	58.7^{a}	42.8^{a}
S4 (50 x 50)	38.9^{b}	38.1^{b}	26.7^{b}	50.3^{b}	38.5^{b}
Mean	41.7	44.0	28.3	57.4	42.9
SEM	0.23	0.27	0.20	0.27	0.18
CV (%)	11.75	15.78	13.57	12.53	15.02
N*S	NS	NS	NS	NS	NS
P-value	0.0003	0.0001	0.0022	0.0001	0.0001

$^{a-c}$ Means followed by different superscripts within a column are significantly different ($P<0.05$); SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

4.3.1.3. Plant height at harvest

The effects of nitrogen fertilizer rate (N) and plant spacing (S) on the plant height of elephant grass are presented in Table 32. Comparable and significantly ($P<0.05$) higher plant height of elephant grass was recorded in treatment N3 and N4 than in N1 and N2 at Holetta, Debre Zeit and in year 2. In year 1 and combined over years and locations, comparable and significantly ($P<0.05$) the highest plant height of elephant grass was recorded in N3 and N4 followed by N2, while the lowest value of plant height was obtained in N1. Generally, elephant grass height was in the order of increasing with increasing nitrogen fertilizer rates (N1 < N2 < N3 < N4). Plant height of elephant grass was comparable and significantly ($P<0.05$) higher in treatment S3 and S4 than in S1 and S2 at Holetta and in year 2. At Debre Zeit, comparable and significantly ($P<0.05$) higher height was recorded in S2, S3 and S4 than in S1. Significantly ($P<0.05$) higher elephant grass height was recorded in S4 than the other three plant spacing configurations (S1, S2 and S3) in year 1. The interaction effect of nitrogen fertilizer and plant spacing was not significant ($P> 0.05$) on elephant grass height except at Holetta and in year 2 ($P< 0.05$).

4.3.1.4. Leaf to stem ratio

Table 33 shows the effects of nitrogen fertilizer application rate (N) and plant spacing (S) on the leaf to stem ratio (LSR) of elephant grass. The LSR value of elephant grass was comparable and significantly ($P < 0.05$) higher in treatment N4 and N3 than N2 and N1 at Debre Zeit, whereas significantly ($P < 0.05$) higher LSR was recorded in N4 than N1 and N2, with the value of N3 falling between the two in year 1. However, LSR was not significantly ($P > 0.05$) affected by the application of nitrogen fertilizer rates at Holetta, in year 2 as well as in the combined analysis over years and locations. Significantly ($P < 0.05$) higher LSR was recorded in S1 than S4, with N2 and N3 having intermediate values between the two at Debre Zeit and in year 1. In the combined analysis over years and locations, comparable and significantly ($P< 0.05$) higher LSR was recorded in S1 and S2 than S4, while S3 had intermediate value between the two. The interaction effect of nitrogen fertilizer and plant spacing was significant ($P< 0.05$) on the LSR of elephant grass at Holetta and in year 2 ($P < 0.05$).

Table 32. Mean plant height (cm) of elephant grass during the establishment year and in the regrowth of the second year as affected by nitrogen fertilizer (kg/ha) and plant spacing (cm) (combined over years and locations)

Treatment	Holetta	Debre Zeit	Year 1	Year 2	Mean
Nitrogen fertilizer (N)					
N1 (0)	59.6^{b}	122.6^{b}	74.1^{c}	108.1^{b}	91.1^{b}
N2 (50)	60.2^{b}	125.3^{b}	77.7^{bc}	107.8^{b}	92.7^{b}
N3 (100)	63.0^{a}	132.7^{a}	81.5^{ab}	114.2^{a}	97.8^{ab}
N4 (150)	64.2^{a}	136.7^{a}	85.4^{a}	115.5^{a}	100.5^{a}
P-value	0.0008	0.0001	0.0001	0.0002	0.0277
Plant spacing (S)					
S1 (75 x 75)	59.0^{b}	123.4^{b}	75.2^{b}	107.2^{b}	91.2
S2 (100 x 50)	58.6^{b}	129.9^{a}	79.2^{b}	109.4^{b}	94.3
S3 (125 x 25)	63.8^{a}	129.9^{a}	79.3^{b}	114.5^{a}	96.9
S4 (50 x 50)	65.5^{a}	134.0^{a}	85.0^{a}	114.5^{a}	99.8
Mean	61.7	129.3	79.7	111.4	95.5
SEM	0.21	0.31	0.29	0.28	0.30
CV (%)	7.00	7.23	10.06	6.50	17.94
N*S	0.0026	NS	NS	0.0392	NS
P-value	0.0001	0.0023	0.0009	0.0008	0.0933

$^{a-c}$ Means followed by different superscripts within a column are significantly different ($P<0.05$); SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

Table 33. Mean leaf to stem ratio of elephant grass forage during the establishment year and in the regrowth of the second year as affected by nitrogen fertilizer (kg/ha) and plant spacing (cm) (combined over years and locations)

Treatment	Holetta	Debre Zeit	Year 1	Year 2	Mean
Nitrogen Fertilizer (N)					
N1 (0)	2.15	1.68^{b}	2.04^{b}	1.80	1.92
N2 (50)	2.20	1.67^{b}	2.14^{b}	1.74	1.94
N3 (100)	2.25	2.04^{a}	2.35^{ab}	1. 94	2.14
N4 (150)	2.24	2.07^{a}	2.57^{a}	1.75	2.16
P-value	0.9077	0.0093	0.0092	0.4709	0.1151
Plant Spacing (S)					
S1 (75 x 75)	2.33	2.11^{a}	2.60^{a}	1.83	2.22^{a}
S2 (100 x 50)	2.22	1.96^{ab}	2.36^{ab}	1.83	2.09^{a}
S3 (125 x 25)	2.23	1.79^{bc}	2.21^{bc}	1.80	2.01^{ab}
S4 (50 x 50)	2.07	1.61^{c}	1.93^{c}	1.74	1.84^{b}
Mean	2.21	1.87	2.27	1.80	2.04
SEM	0.073	0.074	0.077	0.072	0.057
CV (%)	23.22	28.33	25.03	27.39	31.01
N*S	NS	NS	NS	NS	NS
P-value	0.3673	0.0105	0.0012	0.9168	0.0293

$^{a-c}$ Means followed by different superscripts within a column are significantly different (P<0.05); SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

4.3.1.5. Forage dry matter and crude protein yields

The forage DMY and CPY of elephant grass as influenced by nitrogen fertilizer (N) and plant spacing (S) are presented in Table 34. Comparable and significantly (P< 0.05) higher DM yields were recorded in N3 and N4 than in N1 and N2 at Holetta and in the combined analysis over locations. At Debre Zeit, comparable and significantly (P< 0.05) the highest dry matter yield (DMY) values were recorded in N3 and N4 followed by N2, while the lowest value was obtained in N1. The trend of elephant grass DMY was in order of increasing with an increasing in nitrogen fertilizer application rates (N1< N2< N3< N4). At Holetta, Debre Zeit and combined over locations, comparable and significantly ($P < 0.05$) higher DMY values were recorded at S4 followed by S3, S2 while the lowest values were observed in S1. The overall mean DMY figures (5.38 t/ha, 12.23 t/ha) were recorded at Holetta and Debre Zeit, respectively.

Comparable and significantly ($P < 0.05$) the highest elephant grass forage CP yields were recorded in N3 and N4 followed by N2, while the lowest values were observed in N1 at Holetta and over locations. At Debre Zeit, comparable and significantly ($P < 0.05$) higher CP yields were recorded in N3 and N4 than in N1 and N2 treatments. The trend of elephant grass crude protein yield was also increasing with an increase in nitrogen fertilizer rates (N1< N2< N3< N4). At Holetta and over locations, comparable and significantly ($P < 0.05$) higher CP yields were recorded at S4 followed by S3, S2 while the lowest value was recorded in S1. Comparable and significantly ($P < 0.05$) higher CP yields were recorded in S2 and N4 than in S1 treatments, with S3 having intermediate value between the two at Debre Zeit. The overall mean crude protein yield values (0.46 t/ha, 0.96 t/ha) of elephant grass were recorded at Holetta and Debre Zeit, respectively. The interaction effect between nitrogen fertilizer and plant spacing was not significant ($P < 0.05$) on the DM and CP yields of elephant grass.

Table 34. Forage dry matter and crude protein yields (t/ha) of elephant grass forage during the establishment year (Year 1) and in the resgrowth during the second year (Year 2) as influenced by nitrogen fertilizer (kg/ha) and plant spacing (cm) at Holetta and Debre Zeit

Treatment	**Holetta**			**Debre Zeit**			**Overall Mean (DMY, t/ha)**	**Crude protein yield (t/ha)**		**Overall Mean**
	Year 1	Year 2	Mean	Year 1	Year 2	Mean		Holetta	Debre Zeit	
Nitrogen Fertilizer										
N1 (0)	0.41[b]	9.24[b]	4.82[b]	4.86[b]	12.60[d]	8.73[c]	6.77[b]	0.36[c]	0.65[b]	0.51[c]
N2 (50)	0.50[a]	9.74[b]	5.12[b]	5.65[b]	15.49[c]	10.57[b]	7.84[b]	0.45[b]	0.78[b]	0.62[b]
N3 (100)	0.48[ab]	11.24[a]	5.86[a]	6.88[a]	21.06[b]	13.97[a]	9.92[a]	0.52[a]	1.14[a]	0.83[a]
N4 (150)	0.51[a]	10.96[a]	5.74[a]	7.33[a]	23.97[a]	15.65[a]	10.69[a]	0.51[a]	1.25[a]	0.88[a]
P-value	0.0452	0.0007	0.0025	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Plant Spacing										
S1 (75 x 75)	0.33[b]	7.93[c]	4.13[c]	4.65[c]	15.42[c]	10.03[c]	7.08[c]	0.35[c]	0.81[b]	0.58[c]
S2 (100 x 50)	0.36[b]	10.24[b]	5.30[b]	5.81[b]	19.89[ab]	12.85[ab]	9.07[b]	0.45[b]	1.03[a]	0.74[ab]
S3 (125 x 25)	0.59[a]	10.07[b]	5.33[b]	6.07[b]	17.29[bc]	11.68[bc]	8.51[b]	0.45[b]	0.93[ab]	0.69[b]
S4 (50 x50)	0.61[a]	12.94[a]	6.78[a]	8.19[a]	20.53[a]	14.36[a]	10.57[a]	0.58[a]	1.06[a]	0.82[a]
Mean	0.47	10.29	5.38	6.17	18.28	12.23	8.81	0.46	0.96	0.71
SEM	0.045	0.162	0.121	0.157	0.266	0.206	0.144	0.035	0.062	0.042
CV (%)	20.75	12.24	13.08	19.26	18.53	16.59	22.47	13.19	19.27	23.90
N*S	0.0001	0.0001	NS	0.0001	0.0001	NS	NS	NS	NS	NS
P-value	0.0001	0.0001	0.0001	0.0001	0.0021	0.0001	0.0001	0.0001	0.0107	0.0001

[a-d] Means followed by different superscripts within a column are significantly different (P<0.05); N= nitrogen fertilizer; S= plant spacing; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

4.3.2. Forage chemical composition and in vitro dry matter digestibility

Ash, CP, NDF, ADF, ADL and IVDMD of elephant grass forage at different nitrogen fertilizer application rates and plant spacings are presented in Tables 35 to 38.

4.3.2.1. Chemical composition

Table 35 shows the ash contents of elephant grass as affected by nitrogen fertilizer application (N) and plant spacing (S). Comparable and significantly ($P<0.05$) the lower ash contents were obtained in treatment N2, N3 and N4 than N1 at Holetta. At Debre Zeit and in the combined analysis over years and locations, significantly ($P<0.05$) the highest and lowest values were recorded in treatment N1 and N4, respectively with the remaining treatments (N2 and N3) having intermediate values between the two. The effect of plant spacing was not significant on the ash content of elephant grass ($P> 0.05$). The interaction effect between nitrogen fertilizer and plant spacing was not significant on the ash content of elephant grass ($P>0.05$).

Table 36 presents the crude protein (CP) and neutral detergent fiber (NDF) contents of elephant grass as affected by nitrogen fertilizer (N) and plant spacing (S). The effect of N application rates was significant ($P<0.05$) on the CP and NDF contents of elephant grass but that of S was not significant ($P>0.05$) at Holetta, Debre Zeit and in the combined analysis over locations. Comparable and significantly ($P<0.05$) higher CP content was recorded in treatment N2, N3 and N4 than in N1 at Holetta. At Debre Zeit, comparable and significantly ($P<0.05$) higher CP content was obtained in N4 and N3 than in N1 and N2. In the combined analysis over locations, comparable and significantly ($P<0.05$) the highest CP content was obtained in N3 and N4 followed by N2 while the lowest value was recorded in N1. The interaction effect of nitrogen fertilizer and plant spacing was not significant on the CP contents of elephant grass ($P>0.05$).

Significantly (P<0.05) the highest NDF content of elephant grass was obtained in N1 followed by N2 while the lowest was recorded in N3 and in N4 at Holetta. Significantly (P<0.05) higher NDF content was obtained in N1 than the other three nitrogen fertilizer treatments of N2, N3 and N4 at Debre Zeit and the combined effect over locations. The interaction effect of nitrogen fertilizer and plant spacing significantly (P<0.05) affected the NDF contents of elephant grass at Holetta and Debre Zeit, but the effect was not significant (P>0.05) in the combined analysis over locations.

Table 35. Ash content (% on DM basis) of elephant grass forage harvested in the second year of regrowth as affected by nitrogen fertilizer (kg/ha) and plant spacing (cm) at Holetta and Debre Zeit

Treatment	**Ash (% DM basis)**		
	Holetta	Debre Zeit	Mean
Nitrogen Fertilizer (N)			
N1 (0)	18.02^{a}	17.93^{a}	17.97^{a}
N2 (50)	17.20^{b}	17.55^{ab}	17.38^{b}
N3 (100)	16.99^{b}	17.37^{bc}	17.18^{bc}
N4 (150)	17.05^{b}	17.06^{c}	17.06^{c}
P-value	0.0001	0.0008	0.0001
Plant Spacing (S)			
S1 (75 x 75)	17.21	17.42	17.31
S2 (100 x 50)	17.35	17.27	17.31
S3 (125 x 25)	17.35	17.48	17.42
S4 (50 x 50)	17.35	17.75	17.55
Mean	17.32	17.48	17.40
SEM	0.078	0.098	0.064
CV (%)	1.69	2.65	2.26
N*S	NS	NS	NS
P-value	0.5651	0.1115	0.1339

$^{a-c}$ Means followed by different superscripts within a column are significantly different (P<0.05); SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

Table 36. Crude protein (CP) and neutral detergent fibre (NDF) content (% in DM basis) of elephant grass forage harvested in the second year regrowth as affected by nitrogen fertilizer (kg/ha) and plant spacing (cm) at Holetta and Debre Zeit

Treatment	**CP (% DM basis)**			**NDF (% DM basis)**		
	Holetta	D/ Zeit	Mean	Holetta	D/ Zeit	Mean
Nitrogen Fertilizer (N)						
N1 (0)	7.41[b]	7.51[b]	7.46[c]	64.98[a]	64.17[a]	64.58[a]
N2 (50)	8.72[a]	7.56[b]	8.14[b]	62.98[b]	63.71[b]	63.34[b]
N3 (100)	8.81[a]	8.35[a]	8.58[a]	62.26[c]	63.66[b]	62.96[b]
N4 (150)	8.82[a]	8.11[a]	8.47[a]	62.25[c]	63.69[b]	62.97[b]
P-value	0.0001	0.0001	0.0001	0.0001	0.0053	0.0001
Plant Spacing (S)						
S1 (75 x 75)	8.45	8.06	8.26	63.16	63.77	63.46
S2 (100 x 50)	8.42	7.99	8.20	63.15	63.86	63.50
S3 (125 x 25)	8.38	7.82	8.10	63.02	63.73	63.38
S4 (50 x 50)	8.51	7.66	8.09	63.15	63.86	63.51
Mean	8.44	7.88	8.16	63.12	63.81	63.46
SEM	0.080	0.087	0.067	0.092	0.088	0.076
CV (%)	3.67	4.65	5.21	0.64	0.58	1.22
N*S	NS	NS	NS	0.0001	0.0131	NS
P-value	0.7798	0.0578	0.4379	0.8099	0.7573	0.9298

[a-c] Means followed by different superscripts within a column are significantly different (P<0.05; D/ Zeit= Debre Zeit; CP= crude protein; NDF= neutral detergent fiber; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

Table 37 shows the acid detergent fiber and acid detergent lignin contents of elephant grass as affected by nitrogen fertilizer (N) and plant spacing (S). The effect of N application was significant ($P<0.05$) on the ADF and ADL contents of elephant grass but that of S did not significantly ($P>0.05$) affect. The ADF content was significantly ($P<0.05$) higher in treatment N1 than in N2, N3 and N4 at Holetta. Significantly ($P<0.05$) the highest and lowest ADF contents were recorded in treatment N1 and N4, respectively with the remaining two treatments (N2 and N3) having intermediate values between the two at Debre Zeit and the combined effects over locations. The ADL content was significantly ($P<0.05$) higher in nitrogen fertilizer treatment N1 than the other three treatments of N2, N3 and N4 at Holetta. Comparable and significantly ($P<0.05$) higher ADL contents were recorded in N1 and N2 followed by N3 while the lowest value was obtained in N4 at Debre Zeit. In the combined effect over locations, the content of ADL was comparable and significantly ($P<0.05$) higher in nitrogen fertilizer treatments of N1, N2 and N3 than in N4. The interaction effect of nitrogen fertilizer and plant spacing was not significant ($P>0.05$) on the ADF and ADL contents of elephant grass, except on the ADF content at Holetta ($P<0.05$).

Table 37. Acid detergent fibre (ADF) and acid detergent lignin (ADL) content (% in DM basis) of elephant grass forage harvested in the second year regrowth as affected by nitrogen fertilizer (kg/ha) and plant spacing (cm) at Holetta and Debre Zeit

Treatment	**ADF (% DM basis)**			**ADL (% DM basis)**		
	Holetta	D/Zeit	Mean	Holetta	D/Zeit	Mean
Nitrogen Fertilizer (N)						
N1 (0)	41.00[a]	42.47[a]	41.79[a]	5.54[a]	5.55[a]	5.55[a]
N2 (50)	40.73[b]	41.88[b]	41.30[b]	5.53[b]	5.53[a]	5.53[a]
N3 (100)	40.63[b]	41.84[b]	41.23[bc]	5.52[b]	5.47[b]	5.49[a]
N4 (150)	40.69[b]	41.44[c]	41.07[c]	5.52[b]	5.08[c]	5.30[b]
P-value	0.0039	0.0001	0.0001	0.0010	0.0001	0.0001
Plant Spacing (S)						
S1 (75 x 75)	40.78	41.76	41.27	5.53	5.42	5.48
S2 (100 x 50)	40.88	42.03	41.45	5.52	5.41	5.47
S3 (125 x 25)	40.77	41.94	41.36	5.53	5.40	5.46
S4 (50 x 50)	40.71	41.91	41.31	5.52	5.40	5.46
Mean	40.79	41.91	41.35	5.53	5.41	5.47
SEM	0.081	0.091	0.064	0.015	0.034	0.034
CV (%)	0.77	0.94	0.94	0.19	1.03	2.06
N*S	0.0134	NS	NS	NS	NS	NS
P-value	0.6430	0.4088	0.4093	0.0861	0.7283	0.9579

[a-c] Means followed by different superscripts within a column are significantly different ($P<0.05$); D/ Zeit= Debre Zeit; SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

4.3.2.2. In vitro dry matter digestibility

Table 38 shows the *in vitro* dry matter digestibility (IVDMD) of elephant grass as affected by nitrogen fertilizer (N) and plant spacing (S). The effect of N was significant ($P<0.05$) on the IVDMD of elephant grass but that of S was not significant ($P>0.05$). Comparable and significantly ($P<0.05$) higher IVDMD values were recorded in treatment N3 and N4 followed by N2 while the lowest value was obtained in N1 at Holetta and the combined effect over locations. At Debre Zeit, comparable and significantly ($P<0.05$) higher IVDMD values were recorded in treatment N3 and N4 than the other two treatments (N1 and N2). Generally, the trend of IVDMD of elephant grass was increased in the order of nitrogen fertilizer (N1< N2< N3< N4). Plant spacing did not significantly ($P>0.05$) affect the IVDMD values of elephant grass. The overall mean IVDMD of elephant grass was 66.86, 63.94 and 65.40% at Holetta, Debre Zeit and in the combined analysis over locations, respectively. The interaction effect of nitrogen fertilizer and plant spacing was not significant ($P>0.05$) on the IVDMD of elephant grass except at Holetta ($P<0.05$).

Table 38. *In vitro* dry matter digestibility (IVDMD) (% in DM basis) of elephant grass forage harvested in the second year regrowth as affected by nitrogen fertilizer (kg/ha) and plant spacing (cm) at Holetta and Debre Zeit

Treatment	**IVDMD (% DM basis)**		
	Holetta	Debre Zeit	Mean
Nitrogen Fertilizer (N)			
N1 (0)	66.14^{c}	63.43^{b}	64.79^{c}
N2 (50)	66.87^{b}	63.62^{b}	65.25^{b}
N3 (100)	67.21^{a}	64.30^{a}	65.75^{a}
N4 (150)	67.22^{a}	64.40^{a}	65.80^{a}
P-value	0.0001	0.0001	0.0001
Plant Spacing (S)			
S1 (75 x 75)	66.87	63.93	65.40
S2 (100 x 50)	66.77	63.91	65.34
S3 (125 x 25)	66.86	63.88	65.37
S4 (50 x 50)	66.94	64.03	65.49
Mean	66.86	63.94	65.40
SEM	0.086	0.089	0.066
CV (%)	0.54	0.59	0.64
N*S	0.0099	NS	NS
P-value	0.7218	0.7816	0.6602

$^{a-c}$ Means followed by different superscripts within a column are significantly different ($P<0.05$); SEM= standard error of the mean; CV= coefficient of variation; NS= non-significant

5. DISCUSSION

In this section, results from the three experiments are discussed in the orders presented in the preceding section. Therefore, results of forage agronomic performance, subseqent dry matter yield, crude protein yield and nutritive value of intercropping of vetch with elephant grass and elephant grass are discussed as follows.

5.1. Experiment 1-Intercropping of Vetch with Elephant Grass and Plant Spacing

5.1.1. Agronomic performances of elephant grass

5.1.1.1. Survival rate of elephant grass

The mean survival rate percentage of elephant grass in pure stand and vetch intercropping during the the establishment year (year 1) and the regrowth in the second year (year 2) experimental periods was lower than the value (73.4%) reported by Fekede *et al*. (2005) over three years' study period in the central highlands of Ethiopia, but higher than the figure (55.6%) rereported by Ramadhan *et al*. (2015) in Kenya. Vetch intercropping has resulted in lower survival rate of elephant grass in the second year of the regrowth. Vetch intercropped with elephant grass might have dominated the elephant grass which resulted in the drying out of some plants during the dry season when the elephant grass stand was under stress (low moisture and high tempreture). This finding conforms to that of Fekede *et al.* (2005) in a study carried out in the central highlands of Ethiopia. The effect of *V. dasycarpa* and *V. villosa* intercropping decreased in the survival rate of elephant grass by 7.4 and 27.6%, respectively in comparision with pure stand elephant grass over years and locations.

Comparable and significantly higher values of elephant grass survival rate were recorded at wider plant spacing of S1 (75 cm x 75 cm) and S2 (100 cm x 50 cm) than narrower spacings of S4 (50 cm x 50 cm) and S3 (125 cm x 25 cm). This might be attributed to the greater competition of plants for water and soil nutrients when planted at narrower spacing and hence higher plant density. The overall mean survival rate resulting from the combined analysis over years and locations was 59.4%. This value is lower than the reported value (89.9%) from a similar study carried out by Tessema (2005) that involved different accessions of elephant grass assembled from various local sources in the country. The moisture stress, frost and heat stress brought about extremes of temperature in the year of establishment in the experimental period (Figures 2 and 3) could be the probable causes for the recorded low survival rate percentage of elephant grass in the present study.

5.1.1.2. Tillering performance of elephant grass

In this study intercropping of vetches enhanced tillering of elephant grass compared to the pure stand of the grass. However, Fekede *et al*. (2005) found no differences on tillering of elephant grass in pure stands compared with that when it was intercropped with vetches. Tillering is mainly affected by environmental conditions such as air temperature, availability of moisture and soil fertility. Higher number of tillers per elephant grass plant was recorded in the warmer conditions at Debre Zeit than at Holetta in both pure stand and vetch intercropped with elephant grass treatments. The values recorded at Debre Zeit and at Holetta were greater and within the range of 26.4 to 38.2, respectively as reported by Gezahagn *et al*. (2016), on similar studies. Much lower values of tillers (21.3; 15.2) have been reported by Zhang *et al*. (2010) and Halim *et al.* (2013), respectively based on their studies on elephant grass. Furthermore, the mean tiller numbers per plant of elephant grass in year 2 (regrowth) vs year 1 was 58.3 vs 18.0, 60.6 vs 19.8 and 61.9 vs 18.6 for pure stand elephant grass, *V. dasycarpa* intercropped with elephant grass and *V. villosa* intercropped with elephant grass, respectively. This high variation between seasons could be due to the fact that year 1 is the establishment year when plant tends to establish its root system that support tiller emergence in the next growing season. It could as well be due to the perennial nature of elephant grass, which produces more tiller numbers per plant and high vegetative growth with increasing age after establishment as stated by Tessema (2005). Number of tillers recorded in the first year of the present study was lower than that reported for elephant grass by Fekede *et al*. (2005) for Brachiaria grass in Kenya by Nguku *et al*. (2016). About 4.0 and 6.2% more number of tillers per plant of elephant grass was produced in *V. dasycarpa* and *V. villosa* intercropped with elephant grass, respectively than the pure stand elephant grass. This might be due to vetch species domination in the year of establishment of elelphant grass that resulted in some plants loss during the dry season with a subsequent creation of wider spacing of plants and hence lowered competition for water, soil nutrients and light, which in turn enhanced plants to produce more tillers in the following years of establishment. This result is in agreement with the finding of Fekede *et al*. (2005) in similar studies conducted in Ethiopia. In year 2, the mean number of tillers per plant of elephant grass was higher than the value (54.3) in hybrid of elephant grass as reported by Kesang *et al.* (2015) and concurs with the value (60.0) of elephant grass as documented by Nyambati *et al.* (2010).

The number of tillers per plant recorded for elephant grass coincided with the findings of Yasin *et al*. (2003) and Zhang *et al.* (2010) who reported higher number of tillers per plant of elephant grass at wider plant spacing. The number of tillers per plant recorded in the present study was also in line with the findings of Melkie (2005) in Bana grass and Genet *et al*. (2017) in Desho grass who reported that the number of tillers per plant increased with wider plant spacing. This could be due to lower nutrients, water or moisture and light competitions at wider plant spacing of elephant grass. In contrast, at the higher plant density, there is greater competition for light, moisture and soil nutrients with a consequent reduction in the performance of tillering during the growing season (Tessema, 2008; Wijitphan *et al*., 2009; May *et al*., 2016).

5.1.1.3. Harvesting plant height of elephant grass and vetch species at harvest

Elephant grass did not reach the recommended harvesting height of 1.0 to 1.5 m during year 1 harvesting (the establishment year) at Holetta. The present result was coincided with the findings of Fekede *et al.* (2005) and Kariuki *et al.* (2016) based on the same grass species in Ethiopia and Kenya, respectively. It could be due to its slow growth rate of the grass in the cool highlands such as Holetta during the establishment year. Furthermore, vetches as annual crops grew vigorously compared to elephant grass during establishment year at Holetta and these climbing legumes suppressed the growth of elephant grass. However, in the second year of elephant grass establishment attained the recommended harvesting height within three months during the rainy season in the area. The mean elephant grass height at harvest obtained in the present study was in agreement with the finding of Fekede *et al. (*2005) from his study conducted in the central highlands of Ethiopia. While at Debre Zeit, elephant grass achieved the recommended harvesting height in both years (year 1 and 2). Unlike at Holetta, much shorter harvesting height was recorded for vetch species in vetch intercropped with elephant grass at Debre Zeit in both years. This would indicate that elephant grass could better express its full genetic potential under warmer environmental conditions while vetches grow better in cooler areas as compared to warmer areas.

The present result was in agreement with the findings of worku *et al*. (2017) and Genet *et al.* (2017) who reported that Desho grass spacing (125 cm x 100 cm, 100 cm x 0.75 cm, 0.75 cm x 0.5 cm and 0.5 cm x 0.25 cm) and (50 cm x 50 cm, 30 cm x 50 cm and 10 cm x 50 cm), respectively had no significant effect on the plant height at harvest. The overall mean value of elephant grass height was 98.5 cm over years and locations in the present study. The result of this study was closely lower than the figure (109.6 cm) reported by Fekede *et al*. (2005) at Holetta. The low moisture stress encountered, frost and higher maximum temperature in the establishment year of the study period which could be resulted in non-significant effect of plant spacing on elephant grass and vetch species height with the exception of vetch species in the combined effect over locations (Figure 2 and 3). Height of vetch intercropping at harvest was relatively increasing in the order of decreasing plant spacing (S1< S2< S3< S4) in the combined effect over locations. This finding concurred with the value reported by Taleie *et al.* (2012) who showed that taller stevia plants were attained by the closer plant spacing (50 cm × 20 cm). Such an increase in plant height with increased plant density could be due to increased stem growth hormone activity for sun light competition. On the other hand, Mujeeb-ur-Rahman *et al.* (2007) who reported that wider plant spacing resulted in the tallest plant height which was contrary to the present study. It might be due to lesser competition for nutrients, moisture and sun light among the plants.

5.1.1.4. Leaf to stem ratio of elephant grass

Leaf to stem ratio (LSR) of elephant grass forage crops are good indicators of palatability and nutritional values. Leaf is the nutritious part of most plants compared to stems and hence a plant with high LSR is high in its forage quality. The results of LSR in the present study are within the range of values (1.13 to 4.84) reported for a number of elephant grass accessions tested in the central highlands of Ethiopia (Gezahagn *et al*., 2016) and elephant grass cultivars LSR values (0.74 to 3.18) in Malaysia (Zailan *et al*., 2018). While, at Holetta and at Debre Zeit the mean results were higher than the value (1.02) reported from Malaysia and the value (1.38) reported from Uganda (Halim *et al*., 2013; Kawub *et al*., 2014, respectively) for elephant grass. Higher LSR value was recorded for vetch (*Vicia dasycarpa* and *Vicia villosa)* intercropping than pure stand elephant grass according to the result of the combined effect over locations in year 1 and 2. Other documented studies indicate that the values of elephant grass LSR were ranged from 1.7 to 3.1 in Thailand (Tudsri *et al*., 2002b) and from 1.65 to 6.1 in Kenya (Mwendia *et al*., 2006). The findings of the present study were in agreement with these reported ranges. In the present study of the combined analysis over years and locations, the overall mean LSR value (2.21) of elephant grass was recorded. The result of the present study was coincided with the report of Tessema *et al.* (2003) who reported that elephant grass LSR value (1.91) was recorded when planted at 100 cm x 50 cm plant spacing, but higher than the value (1.49) reported by Taye (2004) at a spacing of 50 cm x 50 cm and (1.02) by Halim *et al*. (2013) in elephant grass varieties with plant spacing of 100 cm x 50 cm. The effect of interaction between vetch intercropping and plant spacing was substantial on the elephant grass LSR at Holetta, year 1 and in the combined effect over years and locations. Results of the present study were agreed with the finding of Beyadglign (2019) who reported that the interaction effect of fertilizer, soil type and cultivars was significant on the LSR of grass.

5.1.1.5. Dry matter yields of elephant grass and vetch legumes

Vetch intercropped with elephant grass produced higher total mean DMY (vetch legume plus elephant grass forages) at Debre Zeit than at Holetta. The DMY of vetch intercropping was also influenced by harvesting year and the total mean DM yields were 8.03 and 14.39 t ha^{-1} in year 1 and in year 2 (the regrowth), respectively. Forage crops, *V. dasycarpa* and *V. villosa* intercropping yielded in 67.1 and 72.9% more DMY advantages, respectively than the pure stand elephant grass at Holetta. Similarly, *V. dasycarpa* and *V. villosa* intercropping produced in 11.0 and 6.0% more DMY advantages, respectively than the pure stand elephant grass at Debre Zeit. These might be due to accretion of nitrogen in the soil from the vetch species to the grass through the process of symbiotic nitrogen fixation (Tessema and Baars, 2006). Intercropped forage legumes like vetches achieve competitive advantage in cooler areas like Holetta where the grass component, elephant grass requires more time for establishment while at a later stage it exploits fixed N from the legumes and produce higher forage biomass yield. The combined effect over years and locations vetch intercropped with elephant grass gave higher DMY than the pure stand elephant grass. In the present study, the pure stand elephant grass DMY value (9.47 t ha^{-1}) was in line with the value (9.2 t ha^{-1}) as reported by ILRI (2010). Moreover, vetch intercropping had more DMY advantages of 28.4 and

26.8 % than the pure stand elephant grass, respectively. Substantial difference in DMY was recorded among vetch intercropping and the pure stand elephant grass, and this is in agreement with other results (Fekede *et al*., 2005; Samuel *et al*., 2015). Values from the combined analysis of vetch intercropping and pure stand elephant grass, the present study falls within a range of values 10 to 15 DM t ha^{-1} per year as reported by Seyoum *et al*. (1998) for pure stand elephant grass grown under rain fed conditions at Holetta.

The total DMY of vetch intercropping and pure stand elephant grass increased with increasing of plant density at Debre Zeit and in year 1. In the combined analysis as well showed a comparable trend in the DMY. Moreover, narrower elephant grass spacing of S4 (50 cm x 50 cm) resulted 17.6, 22.8 and 25.6% more DMY advantage over S3 (125 cm x 25 cm), S2 (100 cm x 50 cm) and S1 (75 cm x 75 cm), respectively. These might be attributed to the higher plant density (more number of plants per unit area) at the narrower plant spacings. As in the findings from the present study significantly higher effects of spacing in pure stand elephant grass (50 cm x 80 cm) on the total DM yield as reported by Wijitphan *et al.* (2009). The DMY variations recorded among the tested planting spaces of elephant grass were in agreement with the findings of Yasin *et al.* (2003) and Geren *et al.* (2015) who reported higher forage yields at the narrower plant spacing of pure stand elephant grass (45 cm x 45 cm) in Pakistan and giant king grass (70 cm x 50 cm) in Turkey, respectively. On the contrary, Genet *et al.* (2017) reported that plant spacing (10 cm x 50 cm, 30 cm x 50 cm and 50 cm x 50 cm) had no significant effect on the DMY of Desho grass in the highlands of Ethiopia. The overall mean DMY recorded in the present study was within the range values as indicated by Gezahagn *et al.* (2016, 2017) in which the DMY of elephant grass accessions was ranged between 7.05 to 13.06 t ha^{-1} at a spacing (100 cm x 50 cm) of the grass in Ethiopia. In the present study, the overall mean DMY value (11.22 t ha^{-1}) was as well comparable with the finding of Gezahagn *et al.* (2016) who indicated the DMY value (11.04 t ha^{-1}) of elephant grass at a plant spacing (100 cm x 50 cm) was observed. In general, vetch intercropping and pure stand elephant grass combined over years were produced greater DM yields at Debre Zeit than at Holetta. These could be linked with the condition of warm weather which enhances fast growth, rejuvination and higher DMY of elephant grass.

5.1.2. Forage chemical composition and in vitro dry matter digestibility

Forage yield and quality were highly affected by species composition in intercropping (Ameri and Jafari, 2016). Grass-legume mixtures have multiple advantages of getting high quality forage, economic benefits of effecint use of resources like land, labour and ecological advantages as these forage legumes are an efficient nitrogen source (Havilah, 2011; Longo *et al.,* 2012). The CP content of the present study was considerably higher in vetch *(V. dasycarpa* and *V. villosa)* intercropping than pure stand elephant grass. This result was concurred with the earlier findings of Eskandari *et al.* (2009b); Ojo *et al*. (2013) and Gulwa *et al.* (2017, 2018) who indicated those legumes have the potential to increase the CP contents of the herbage mixtures compared with grass monoculture. The final concentration of the CP content in the present study was above the minimum level (7.0%) required for optimal rumen function in vetch intercropping combined over years and locations. Except over years at Debre Zeit and over locations in year 2 in pure stand elephant grass; the present finding was agreed with the results of other studies in elephant grass (Tessema, 2008; Ferreira *et al.*, 2018) and in guinea grass (Jusoh *et al*., 2014).

Elephant grass spacing in vetch intercropping was not substantially affected the CP content in the present study. This result was in agreement with the previous report of Tessema (2008) who showed that non-significant effect of spacing (150 cm x 25 cm, 100 cm x 25 cm, 50 cm x 25 cm, 150 cm x 50 cm, 100 cm x 50 cm, 50 cm x 50 cm, 150 cm x 75 cm 100 cm x 75 and 50 cm x 75 cm) on the CP contents of elephant grass. Sumran *et al*. (2009) was also supported that elephant grass spacing (50 cm x 100 cm , 50 cm x 80 cm , 50 cm x 60 cm, and 50 cm x 40) did not have substantial effect on the CP contents of elephant grass (*Pennisetum purpureum*) intercropped with or without lablab (*Lablab purpureus*). Conversely, Berihun (2005) reported that the combination of row and plant spacing was greatly affected the CP contents of Bana grass in the semiarid areas of north western Ethiopia. These variations of the CP content with the present study could be attributed to the differences of management practices and environmental conditions.

The ash content of vetch (*V. dasycarpa* and *V. villosa)* intercropped with elephant grass was significantly lower than pure stand elephant grass. The present result was agreed with the findings of Usman (2014) in elephant grass intercropped with or without lablab in Ethiopia and Njoka-Njiru *et al*. (2006) in elephant grass intercropped with herbaceous legumes in the semi-arid regions of Kenya. On the other hand, the present finding was in disagreement with the reports of Alalade *et al.* (2014) and Foster *et al*. (2014) showed higher ash content was recorded in grass-legume mixture than in pure stand grass. Such variations could be attributed to the differences of variety/ species of forage, management and environmental conditions. The ash content of the present study was not significantly affected by spacing of elephant grass. This finding was agreed with finding of Tessema (2008) who reported that non-significant effect of spacing (150 cm x 25 cm, 100 cm x 25 cm, 50 cm x 25 cm, 150 cm x 50 cm, 100 cm x 50 cm, 50 cm x 50 cm, 150 cm x 75 cm, 100 cm x 75 cm and 50 cm x 75 cm) on the ash content of the same species grass. In contrast to the present study, Genet *et al*. (2017) reported significant effect of plant spacing on the ash content of desho grass.

The NDF content of roughage diets ranged from 45-65 and below 45%, which are generally considered as medium and high quality feeds, respectively (Singh and Oosting, 1992). The NDF content of elephant grass forage intercropped with vetches (*V. dasycarpa* and *V. villosa)* was closer to medium-quality feed (45- 65%) category, except in pure stand elephant grass and in year 2 over locations which had higher NDF contents. The NDF content of vetch (*V. dasycarpa* and *V. villosa)* intercropping was lower than pure stand elephant grass in the present study. This result was agreed with the findings of Taye *et al.* (2007) and Usman (2014) in elephant grass intercropped with lablab or Desmodium, and lablab, respectively. According to Usman (2014), elephant grass intercropped with lablab had no significant effect on the ADF content which was in lined with what was reported in the present study. On the contrary, Taye *et al.* (2007) reported that there was a significant effect of elephant grass intercropped with lablab or Desmodium on the ADF content. The ADL content of vetch (*V. dasycarpa* and *V. villosa)* intercropping was considerably higher than pure stand elephant grass in the present study. This result was agreed with the finding of Taye *et al.* (2007) who indicated that elephant grass intercropped with lablab or Desmodium had significantly higher ADL content than pure stand elephant grass. The ADL content was higher in the legumes compared to elephant grass and this also caused an escalation of the ADL content in legumes intercropped with elephant grass harvesting at 90 and 120 days. The result of the present study might be expected due to greater ADL content in the tropical legumes than grasses (Van Soest, 1994). On the contrary, elephant grass intercropped with or without lablab had no significant effect on the ADL content (Usman, 2014).

The different spacing of elephant grass was not significantly affected the NDF, ADF and ADL contents in the present study. These findings were in lined with the report of Tessema (2008) who showed that no significant effect of elephant grass spacing on the NDF, ADF and ADL contents. On the contrary, Berihun (2005) was reported that plant spacing configurations (100 cm x 50 cm, 100 cm x 75 cm, 75 cm x 50 cm and 75 cm x 75 cm) significantly affected the NDF, ADF and ADL contents of Bana grass in semiarid areas of north western Ethiopia. Furthermore, Sumran *et al*. (2009) reported that elephant grass spacing configurations (50 cm x 100 cm, 50 cm x 80 cm, 50 cm x 60 cm and 50 cm x 40 cm) had significant effect on the NDF content and non- significant effects on the ADF and ADL contents.

The IVDMD of elephant grass forage when intercropped with vetches (*V. dasycarpa* and *V. villosa*) were higher than pure stand elephant grass. Legume interropping increased the CP and decreased the NDF contents of the companion crops like elephant grass as the legumes are a good source of fixed nitrogen (Eskandari *et al*., 2009). Legumes intercropping with grasses could contribute to improve the forage nutritional quality (Nadeem *et al*., 2010). Lower NDF content has been associated with increasing digestibility and feed intake (McDonald *et al*., 2002). The IVDMD of elephant grass in the present study was higher than the digestibility of most tropical grasses (54%) (Minson, 1990). The digestibility of elephant grass forage intercropped with vetch (*V. dasycarpa* and *V. villosa*) was considerably higher than pure stand elephant grass and this result was in lined with the findings of Njoka-Njiru *et al.* (2006) and Usman (2014) who reported in herbaceous legumes intercropped with elephant grass had greater digestibility than pure stand elephant grass. The variations could be attributed to the increased nitrogen content obtained from biological fixation of atmospheric nitrogen (N_2) by the legumes. Minson (1990) was also supported that intercropping of perennial tropical grasses with forage legumes enhance pasture quality through increased CP and reduced NDF contents, which was coincided with the result of the present study. The different planting spacings of elephant grass were not significantly affected on the IVDMD. This result was coincided with the finding of Wijitphan *et al*. (2009) who reported that the dry matter digestibility of elephant grass was not significant at plant spacing configurations (50 cm x 40 cm, 50 cm x 60 cm, 50 cm x 80 cm and 50 cm x 100 cm). On the contrary, Berihun (2005) reported that bana grass spacing had significant effect on the *IVDMD*.

5.1.3. Dry matter degradability and degradability characteristics of elephant grass-vetch legume mixture by intercropping

5.1.3.1. In sacco dry matter degradability

Significantly higher *in sacco* dry matter degradability (DMD) of elephant grass forage was recorded in vetch intercropped plots than pure stand elephant grass at all incubation hours (6-96) at Holetta and Debre Zeit. The present study was coincided to the findings of Tessema and Baars (2004) and Njoka-Njiru *et al.* (2006) who reported those legumes had considerable greater effect on the DMD of elephant grass. The present study was also agreed with the report of Usman (2014) who observed that considerably higher DMD was recorded in lablab intercropping than pure stand elephant grass at 6, 12 and 24 hours of incubation except the significant degradability at 48 hours and insignificant figures at 24 and 96 hours of incubation. Similar to the present study, *in sacco* DMD was increased progressively as the incubation hours (6 - 96) increased during wet and dry seasons as reported by Gebreyohannes *et al.* (2006) and Bizelew (2012) in the other grass species and Camacho *et al.* (2010) and Bizelew (2012) in browse species. Substantially higher interaction effect of elephant grass DM degradability was recorded in vetch intercropping than pure stand elephant grass at 6, 12 and 96 hours of incubation. The higher degradability could be associated with the greater CP content owing to vetch intercropping which provides more nitrogen for microbial utilization. On the other hand, Adugna and Sundstøl (1999) showed that the variation of DMD might be caused by the NDF, cellulose and hemicellulose contents. Generally, the highest *in sacco* DMD was recorded at 96 hours of incubation period and the lowest value was recorde at 0 hour of incubation period in all vetch intercropping treatments in the present study. This result was agreed with the findings of Klopfenstein *et al*. (2001) as the period of incubation increased from 0 to 96 hours in the forage and Negash *et al.* (2017) who revealed that from 6 to 96 hours of incubation in oats grown in mixture with vetch with or without phosphorous fertilization, respectively in the rumen increased the *in sacco* DMD in East shewa zone of Ethiopia. The i*n sacco* DMD has a practical implication as there is affirmative relationship between degradability and voluntary feed intake and digestibility (Adugna and Sundstøl, 2001).

5.1.3.2. In sacco degradability characteristics

At Holetta, significantly higher dry matter degradabilitry (DMD) characteristics of elephant grass forage were recorded when intercropping with vetch species than pure stand except for the potentially, but slowly degradable fraction (“b”). The present study was concurred with the finding of Njoka-Njiru *et al.* (2006) who reported that the effective degradability (ED) was significantly higher in lablab intercropping than pure stand elephant grass. However, the present study was disagreed with the finding of Njoka-Njiru *et al.* (2006) who observed that non significant effect of lablab intercropping on the DMD characteristics ("a", "b", "c" and PD) of elephant grass. At Debre Zeit, significantly higher DMD characteristics were recorded in *Vicia villosa* intercropping than *Vicia dasycarpa* intercropping and pure stand elephant grass except the rapidly degradable fraction of *Vicia villosa* intercropping. At Holetta, the rapidly degradable fraction of pure stand elephant grass was lower than vetch intercropping with elephant grass. The present study was concurred with the finding of Usman (2014) in lablab intercropping. However, at Debre Zeit the highest rapidly degradable fraction was recorded in *Vicia dasycarpa* intercropping followed by pure stand elephant grass and the lowest was observed in *Vicia villosa* intercropping. These inconsistent values were partially agreed with the report of Usman (2014) who showed that significantly higher fraction was recorded in pure stand elephant grass than lablab intercropping. The rapidly degradable fraction is an essential characteristic of roughage since the contribution of the rapidly degradable fraction to the gut fill is little and almost completely digestible (Ørskov, 1998). At Holetta, potentially, but slowly degradable fraction was higher in pure stand elephant grass than vetch intercropped with elephant grass. This result was disagreed with the other study (Usman, 2014). The potentially but slowly degradable fraction was comparable and lower in pure stand elephant grass and *Vicia dasycarpa* intercropping than *Vicia villosa* intercropping with at Debre Zeit. The present study at Holetta and Debre Zeit were concurred and disagreed with finding of Usman (2014), respectively. The PD and ED fractions were higher in vetch intercropping than pure stand elephant grass at Holetta and Debre Zeit. The PD of the present study was a bit lower than as reported by Kariuki (1998) in elephant grass and Njoka-Njiru *et al.* (2006) in lablab intercropping while the ED was higher than those reported by Tessema *et al*. (2002a) in elephant grass at different harvesting height and Njoka-Njiru *et al.* (2006) in lablab intercropping. The rate of degradation was significantly higher in vetch intercropping than pure stand elephant grass at Debre Zeit. However, the present study was disagreed with the finding of Usman (2014) who reported that non-significant differences was observed in the rate of degradation in lablab intercropping and pure stand elephant grass.

5.2. Experiment 2- Harvesting Heights of Elephant Grass and Nitrogen-Fertilizer Rates

5.2.1. Forage agronomic performances

5.2.1.1. Survival rate

Survival rate percentage is a crucial consideration in forage crop cultivation due to its substantial effect on forage productivity. Elephant grass can be propagated from root splits or stem cuttings, and estabishmnet could vary across agro-ecologies (Getnet and Gezahagn, 2012). Plants from root splits make hastier early growth and give high forage yields than from stem cuttings. Furthermore, mature stems are more reliable than young stems for ease of establishment and tiller performances (Woodard *et al*., 1991). The survival rate of elephant grass decreased with increasing age of harvesting over locations in the present study. This result concurred with the finding of Getnet *et al*. (2012) in multipurpose forage species, in the central highlands of Ethiopia. The average survival rate of elephant grass tested over two years was 75.6% at Holetta. This result concurred with the report of Fekede *et al.* (2005) who stated that the average survival rate of elephant grass during experimental period of the three years was 73.8%. Moreover the value is lower than what was reported by Tessema and Alemayehu (2010) who recorded the average stands count to be 89.6% for elephant grass accessions at 100 cm height of harvesting. Similarly, the average survival rate at Debre Zeit, in year1 (establishment), year 2 (regrowth production) and in the combined analysis of over years and locations was 56.4, 67.7, 64.3 and 66.0%, respectively. The present results were lower than the finding of Fekede *et al.* (2005) for the same species and that of Tessema and Alemayehu (2010) for a number of elephant grass accessions. The lower survival rate at Debre Zeit

(56.4%) might be due to severe frost and moisture stress during 2016 establishment year. However, there was no significant effect on the forage yield due to the lower survival rate of elephant grass, which could be attributed to low competition for available nutrients and water which resulted in vigorous growth of tillers produced by the survived elephant grass plants.

The survival rate of elephant grass was low in the regrowth production (year 2) as compared to year 1 (the establishment year). This result was in line with the finding of Fekede *et al.* (2005) in the same species of grass. It could be attributed to the death of some stands of elephant grass during the dry seasons. As the rates of nitrogen fertilizer application increased from N1 to N4, the survival rate of elephant grass forage also increased at Holetta, Debre Zeit, in year 1, year 2, and in the combined analysis over years and locations. The present study was coincided with the finding of Premaratne and Premalal (2006) who reported that the application of recommended NPK (120-60-50 kg/ha) fertilizer rate increased on the survival rate of the grass. In contrast, the rate of DAP (100 kg/ha) fertilizer application had no significant effect on the survival rate of the elephant grass at Holetta (Fekede *et al.*, 2005). These might be due to the differences of soil fertility, environmental condition and management practices.

The interaction effect of harvesting height and nitrogen fertilizer rate affected the survival rate of elephant grass at Holetta. This finding is contrary to the finding of Bizelew *et al*. (2020) who reported that non-significant effect of vetch intercropping and plant spacing on the survival rate of elephant grass over years and locations. It could be attributed to the differences in management practices such as plant spacing, vetch intercropping, nitrogen fertilization and harvesting height of elephant grass.

5.2.1.2. Tillering performance

Plant growth characteristic in response to the different harvesting height, demonstrating that harvesting influences the forage morphological development and quality (Tessema, 2005; Halim *et al*., 2013). The significant decline in the number of tillers with increasing stages of harvesting height in elephant grass was in line with the findings of other studies (Clavero, 1997; Onyeonagu and Asiegbu, 2012; Kesang *et al*., 2015). The low number of tillers per plant produced under extended harvesting height has been linked to higher tillers mortality under reduced intervals of harvesting frequency (Clavero, 1997). On the contrary, Tessema *et al. (*2003) reported that the number of tillers per plant increased with increasing elephant grass harvesting height. The variations could be attributed to the differences in soil fertility and environmental conditions.

The effect of nitrogen fertilizer was significantly higher especially at higher application rates on the number of tillers per plant (NTPP) of elephant grass over years and locations. This result concurred with the findings of other studies (Kizima *et al*., 2014; worku *et al*., 2017) in *Cenchrus ciliaris* and desho grasses, respectively. The highest NTPP was found on elephant grass when nitrogen fertilizer applied at a rate of N4 (150 kg ha^{-1}) followed by N3 (100 kg ha^{-1}), N2 (50 kg ha^{-1}) and the lowest was recorded in N1 (Control). This result agreed with the finding of Rahman *et al*. (2016) who reported that the NTPP increased with increasing rate of nitrogen fertilizer application in the same species of grass. Similarly, Zahid *et al*. (2002) and Fekede *et al. (*2005) revealed that nitrogen fertilizer application enhanced the production of more NTPP of elephant grasses. According to Mushtaque *et al.* (2010) the application of nitrogen fertilizer in buffel grass stimulated the activation of dormant buds and enhanced the NTPP. Generally, the NTPP of elephant grass in the present study increased in the order of increasing nitrogen fertilizer rate (N1< N2< N3< N4).

5.2.1.3. Leaf to stem ratio

Higher leaf to stem ratio (LSR) is substantial from the forage viewpoint because it is the central factor that affecting forage selection, quality and intake (Smart *et al.,* 2004; Zailan *et al.,* 2018). Livestock performance is associated to the amount of leaf in the forage diet (Tudsri *et al*., 2002a). The highest LSR of elephant grass was recorded at HH1 followed by HH2 while the lowest value was observed at HH3 the combined effects over years and locations. The trend of LSR in the present study was decreased with progressive increasing of harvesting height (HH1 > HH2 > HH3). This is directly releated to the ages of the plant, as the stage of the plant advanced to maturity the leaf to stem ratio declines. This observation is also reported in the findings of other researchers (Smart *et al.,* 2004; Vendramini, 2010; Tessema *et al*., 2010; Mimila, 2018). The decrease in LSR with increasing in harvesting height of elephant grass growth proposed that leaf mass does not increase in the same ratio as stems. Therefore, aforementioned trend of growth is one of the main reasons for decreasing forage quality from the declined ratio of leaves in the total biomass of forage. Correspondingly, according to Butt *et al*. (1993) and Kesang *et al*. (2015) the reduced LSR of elephant grass with extended harvesting intervals (ages) is a function of physiological growth due to the reduced harvesting frequency that triggers growth of stem at the expense of leaf production. In the present study, the combined analysis of LSR values (1.63 - 2.63) of elephant grass at the range of harvesting height from 50 cm to 150 cm was higher than the LSR values (0.44-0.55) of the same species of grass with harvesting height ranged from 120 cm to 150 cm as reported by Ferreira *et al*. (2018). However, the LSR value (1.96) of the present study at HH2 (100 cm) was higher than (1.33 LSR; 1.00 LSR) what was reported by Tessema *et al.* (2003) and Tessema (2008), respectively in the same species of grass.

The effect of nitrogen fertilizer application rates on the LSR of elephant grass was higher in treatments N3 and N4 than N1 and N2 at Holetta, Debre Zeit, in year 2 and combined over years and locations. The LSR of elephant grass was significantly greater at higher rates of nitrogen fertilizer applications. The present result was in lined with the finding of Assaeed (1994) who reported that LSR of fodder oats (*Avena sativa* L.) was increased in response to increase rates of nitrogen fertilizer applications. Similarly, Yossif and Ibrahim (2013) confirmed that LSR of Rhodes grass was increased by increasing nitrogen fertilizer rates. The present study was also supported by the finding of Tariq *et al.* (2011) who revealed that the role of nitrogen fertilizer with respect to LSR was significant and higher at higher rates and it could be largely attributed to more leaf mass production per plant. On the other hand, the effect of nitrogen fertilizer application rates was not significant on the LSR of elephant grass in year 1. This finding was concurred with the report of Flores *et al*. (2012) who found that significant differences was not recorded between nitrogen fertilizer rates (0 and 100 kg ha^{-1}) on the LSR of elephant grass.

5.2.1.4. Forage dry matter and crude protein yields

Substantial variations in forage DMY among the three harvesting height of elephant grass treatments could chiefly be related to the differences of stand age. The effect of harvesting height and nitrogen fertilizer treatments on the DMY of elephant grass ranged between 3.93 to 6.24 t ha^{-1} and from 4.48 to 6.12 t ha^{-1}, respectively, with a mean value of 5.41 t ha^{-1} at Holetta. At Debre Zeit, the DMY ranged from 8.60 to 14.75 t ha^{-1} in the harvesting height and between 9.00 to 13.47 t ha^{-1} in nitrogen fertilizer treatments with a mean value of 11.87 t ha^{-1}; these considerable DMY varations were recorded within treatments. This result was concurred with the findings of other studies (Ansah *et al*., 2010; Obok *et al.*, 2012). It could be the proportional increment of DMY with the age of elephant grass (Taye *et al*., 2007); this could be also supported by the differences of environmental conditions (moisture, light intensity and temperature) and soil fertility (Campos *et al*., 2013). Elephant grass DMY value was increased with the increase of nitrogen fertilizer application rates. This result was agreed with the other studies of Hazary *et al.* (2015) in jumbo grass and Galindo *et al.* (2017) in guinea grass.

The CP yield of elephant grass was also varied among harvesting height and nitrogen fertilizer treatments, which generally linked to the forage biomass yield. The present finding was indicated that the CPY ranged between 0.39 to 0.57 t/ha at harvesting heights of elephant grass and from 0.39 to 0.57 t/ha in nitrogen fertilizer treatments with a mean value of 0.50 t/ha at Holetta. In the same way, at Debre Zeit the CPY ranged from 0.73 to 1.23 t/ha at harvesting heights and from 0.73 to 1.15 t/ha in nitrogen fertilizer rates with a mean of 1.00 t/ha. The CP content should not be used as the only parameter in evaluating forage crops; the CPY demarcates the overall and actual productivity of forage quality.

5.2.2. Forage chemical composition and in vitro dry matter digestibility

One of the main nutrients in forage quality determination is the CP content, since the dry matter intake and growth of ruminal microbs enhance with escalating the CP content in a feed (Chanthakhoun *et al*., 2012). The increased in elephant grass HH was resulted in the reduction of CP content and IVDMD in the present study. These results were coincided with the report of Tessema *et al.* (2002) in the same species of grass. Significantly the highest CP content was recorded in HH1 (the early harvesting height) compared to HH2 (the intermediate) and HH3 (the late stages of harvesting height). These might be predominantly due to the CP content dilution in the forage by the rapid cell wall carbohydrates buildup at the later phases of growth (Van Soest, 1994). In other findings, elephant grass CP contents were diminished with maturity or age of forage crops (Ansah *et al*., 2010; McDonald *et al*., 2010; Jusoh *et al*., 2014; Rambau et *al*., 2016). In the present study, the overall mean CP content (8.9%) of elephant grass was higher than the value (5.4%) as reported by Deribe *et al.* (2017) at 100 cm harvesting height in distinct accessions of elephant grass. The final CP content at different harvesting heights exceeded the minimum CP level (7.0%) required for optimal rumen function in the present study of elephant grass. This result was coincided with the findings of other studies (Tessema, 2008; Ferreira *et al.*, 2018) in elephant grass and Jusoh *et al*. (2014) in guinea grass. Correspondingly, Taye *et al.* (2007) and Ansah *et al.* (2010) were reported a diminishing trend of CP content with escalating of elephant grass harvesting height (HH1 > HH2 > HH3). The CP content of elephant grasss was considerable among the nitrogen fertilizer treatments at Debre Zeit and in the combined analysis over locations and it was above the threshold level at Holetta, Debre Zeit and in the combined analysis over locations. This result was concurred with the finding of Arshad *et al.* (2010) in elephant grass.

The ash content of elephant grass was significantly varied in the different harvesting height at Holetta. The present study was concurred with the finding of Adane and Berhan (2007) in the natural pasture. The declined in the ash content with increased harvesting height of elephant grass was could be caused by partly the effect of higher yields dilution in the availability of a constant amount of minerals in the soil. This finding was concurred with the other observations (McDonald *et al*. 2002; Rao *et al*., 2007). Similarly, according to Taye *et al. (*2007) the ash contents of herbaceous forages were declined as the maturity stage advances. The ash content of the present study was decreased numerically due to increased rate of N at Holetta, Debre Zeit and in the combined analysis over locations. This result was in lined with the finding of Khan *et al.* (1996) who reported that applications of higher nitrogen fertilizer rates reduced oat fodder ash contents. This could be due to soil characteristics, fertilization regime, climatic conditions, plant developmental stage and morphological fractions (McDowell and Valle, 2000; Jukenvicius and Sabiene, 2007).

The NDF content was significantly increased from HH1 to HH3 at Holetta, Debre Zeit and in the combined analysis over locations. The present result was concurred with the findings of other studies (Bovolenta *et al*., 2008; Ansah *et al*., 2010*;* Salamone *et al.,* 2012) who reported that the NDF content was increased progressively as the forage maturity increased. Moreover, the overall mean NDF content of elephant grass in the present study at different harvesting height and nitrogen fertilizer rates were reported within the range of medium quality roughage feeds (45 - 65%) suggested as reported by Singh and Oosting (1992). At Holetta and in the combined analysis over locations, the NDF contents of elephant grass were significantly higher in N1 than N2, N3 and N3 applications which were concurred with the report of Khaleduzzaman *et al.* (2007) in the same species of grass. The ADF content was comparable and significantly higher at HH2 and HH3 than at HH1 at Holetta, Debre Zeit and the combined effect over locations. These findings were coincided with the report of Tessema and Alemayehu (2010) who reported that the NDF and ADF contents were increased with increasing of elephant grass harvesting height. Acid detergent fiber is the proportion of significantly indigestible and gradually digestible of forage. As with NDF, higher ADF contents resulted in reduced forage DM digestibility due to increased lignification of cellulose (Depeters, 1993). The ADF content of elephant grass was in the order of decreasing with increasing nitrogen fertilizer rate (N1 > N2 > N3 > N4). This result was coincided with the reports of Lee and Lee (2000) and Galindo *et al.* (2017) who found the ADF content was reduced with the increasing rates of nitrogen fertilizer applications. The ADL content of the present study was comparable and significantly higher at HH2 and HH3 than at HH1 at Debre Zeit and the combined effect over locations. This result was agreed with the findings of other studies (Moreira *et al*., 2004; Taye *et al.,* 2007; Bovolenta *et al*., 2008) who recorded that the ADL content of elephant grass increased with advanced maturity stages. Forage harvesting height at the late stage, had the highest lignin content indicating that the lignin content would bind the hemicellulose and cellulose and inhibit them from being efficiently digested and utilized by microbes of the rumen (Moreira *et al*., 2004; Bovolenta *et al*., 2008; Ansah *et al*., 2010). Moreover, Van Soest (1982) supported that forage digestibility was more influenced by the ADL content than other chemical components.

Elephant grass harvesting height was reported to have a considerable effect on the *in vitro* dry matter digestibility (IVDMD). As harvesting height increased from HH1 to HH3, there had been a decreased in IVDMD from 68.68- 66.69%. This finding was within the range values (61-72%) as reported by Tessema and Alemayehu (2010). According to Taliafero *et al.* (1975) and Tessema *et al.* (2002a) reported that harvesting of grasses at increased defoliation interval had reduced the IVDMD contents. The nitrogen fertilizer treatment on elephant grass IVDMD was also significantly varied and increased with increasing nitrogen fertilizer rates at Debre Zeit and in the combined effect over locations. This study was coincided with the other studies of Tegegn (2001) and Naroon *et al.* (2006) who reported that the application of different nitrogen fertilizer rates had considerable effects on *Panicum coloratum* IVDMD at all harvesting height stages and across four grass species, respectively. The critical threshold level (50%) of feeds IVDMD considered as having acceptable digestibility (Owen and Jayasuriya, 1989). In the present study, elephant grass IVDMD was higher than (65%) and it was within acceptable ranges reported previously by Owen and Jayasuriya. In general, the IVDMD content of any forage crop varies with the stage of harvesting (Zinash *et al.* (1995); fiber and cell wall constituents (Van Soest, 1994); proportions of morphological portions (Fekede, 2004), and soil, plant species and climate (McDowell, 2003).

5.2.3. Dry matter degradability and degradability characteristics of elephant grass

5.2.3.1. In sacco dry matter degradability

The dry matter degradability (DMD) allows the description of the quantity of nutrients degraded effectively in the rumen of livestock and the outflow rate of feed from the rumen (Susmel *et al*., 1990). The decline in rumen DMD with maturity (age) of plant growth has been showed extensively (Silva *et al*., 2008; Belachew *et al*., 2013; Ribeiro Junior *et al*., 2014). This reduction in disappearance could be explained by the reduction of CP content and escalation of ADL content in grass with maturity. The *in sacco* DMD of elephant grass was significantly affected by harvesting height (HH) at all incubation hours (6-96) at Holetta and Debre Zeit. This result was concurred with the value of elephant grass cutting height which was significantly affected on the *in sacco* DMD incubated up to 120 hours (Tessema *et al*., 2002b). In contrast, Rambau *et al*. (2016)

indicated that non-significant variations of *in sacco* DMD of elephant grass leaves at three stages of maturity at all incubation hours (0-120). In the present study, the reduction in DMD was considerably greater when the grass matured. This result was concurred with the finding of Baloyi *et al.* (2008) who recorded a decrease in DMD with advanced stage of maturity of Cow pea and Silver leaf desmodium forage legumes. As projected, the disappearance of DM escalated with increasing time of incubation, but decreased with advanced stages of maturity or harvesting height. Generally, the trend of *in sacco* dry matter degradability of elephant grass was declined at any given incubation hour in the order of HH1> HH2 > HH3. It could be attributed to the declined in the crude protein content and the increased in the structural components of elephant grass.

5.2.3.2. In sacco degradability characteristics

The significant effect of harvesting height (HH) was recorded on the DMD characteristics of elephant grass at Holetta and Debre Zeit except the potentially, but slowly degradable fraction “b” and the rate of degradation of “b” fractions “c” at Debre Zeit. The present study was disagreed with the finding of Njoka-Njiru *et al.* (2006) who observed that non-significant effect of lablab intercropping on elephant grass DMD characteristics except the effective degradability (ED). Rambau *et al.* (2016) also reported that non- significant effect of DMD characteristics of elephant grass leaves, except the rapidly degradable fraction “a” and ED at the three stages of maturity. The highest “a” fraction of elephant grass could be explained by the lowest NDF content across the harvesting heights. The PD and ED values reveal the extent of the fermentation of the forages DM in the rumen. The PD and ED of elephant grass at rumen outflow rate of 0.03 h^{-1} were comparable for PD and higher for ED at HH1 (50 cm) and HH2 (100 cm) than HH3 (150 cm) at Holetta and Debre Zeit. This could be explained by the increasing of leaf to stem ratio (LSR) of elephant grass in the order of harvesting height (HH1 > HH2 > HH3) at both locations. The present study might be also attributed to the increase in cell wall constituents and the decrease in LSR at a higher harvesting height (age). The present finding was concurred with the reports of other studies (Seyoum *et al*., 1998; Tessema *et al*., 2002b) in elephant grass. The degradation rate "c" values of elephant grass were not significant in the present study at Debre Zeit. These results were concurred with the finding of Bamikole *et al*. (2004) who reported that the "c" values of *Panicum maximum* and *Stylosanthes hamata* in Nigeria were not significantly different, unlike to Holetta where the "c" figures were significant. Kabuga and Darko (1993) showed that the decreasing of DMD linearly with increasing growth age of grass species in the tropics. Similarly, Tessema *et al*. (2003a) and Soares *et al*. (2004) reported that maturity has a dramatic decreased effect on the dry matter degradability of elephant grass.

5.3. Experiment 3- Fertilizer Rate and Plant Spacing of Elephant Grass

5.3.1. Forage agronomic performances

5.3.1.1. Survival rate

The survival rate percentage of elephant grass was increased as the rate of nitrogen fertilizer applications increased at Holetta, in year 1 and combined over years and locations. Fekede *et al.* (2005), and Premaratne and Premalal (2006) reported that basal application of DAP (100 kg/ha) and NPK (120 - 60 - 50 kg/ha) fertilizer rates had no significant effect and increased the survival rate of the grasses; these were coincided and disagreed what was presented in the present study, respectively. The survival rate of elephant grass was decreased during the second year of establishment as compared to the establishment year. This result was agreed with the finding of Fekede *et al.* (2005) in the same species of grass. It could be attributed to the seasonal variations and the length of the dry season, which could affect the survival rate of the grass.

The survival rate of elephant grass was significantly higher at a plant spacing of S1 and S2 (wider plant spacings) than in S3 and S4 (narrower spacings) at Holetta, in year 1 and in the combined analysis over years and locations. At Debre Zeit and in year 2, comparably higher survival rate was recorded in treatment S1 and S2 than S3 and S4. However, the trend of survival rate percentage in elephant grass was in the order of increasing with successive increasing of plant spacing (S4 < S3 < S2 < S1). The overall mean survival rate value (64.6%) of this study was lower than the values (73.4%; 72.0%) as reported by Fekede *et al*. (2005) at Holetta, and Getnet and Gezahagn (2012) at Ginchi, respectively in the same spicies of elephant grass spacing (100 cm x 50 cm). Despite that it was observed the decreased survival rate of elephant grass that did not affect the forage yield, and this could be attributed to the vigorous growth performance of the number of tillers per plant produced at lowr densities of the survived plants, but the value of this study was greater than the figure (55.6%) as reported by Ramadhan *et al*. (2015) in the same species of grass at 100 cm x 50 cm spacing in Kenya.

The interaction effect of nitrogen fertilizer and plant spacing was significantly affected on the survival rate of elephant grass over years and locations. The result of this finding was disagreed with the finding of Bizelew *et al*. (2020) who reported that non - significant effect of vetch intercropping and plant spacing on the survival rate of elephant grass over years and locations. This could be attributed to the differences in the type of management practices employed such as vetch intercropping and application of nitrogen fertilizer rates on elephant grass.

5.3.1.2. Tillering performance

The application of nitrogen fertilizer (N) rates was significantly increased the number of tillers per plant (NTPP) of elephant grass over years and locations. This result was agreed with the findings of other studies (Okeagu, 1991; Kizima *et al*., 2014; 2016; worku *et al*., 2017) who reported the NTPP were increased in response to successively increased N rates in other grass species. This finding was also supported by Mushtaque *et al*. (2010) who reported that N application stimulates the activation of dormant buds and increases the NTPP of buffel grass. On the contrary, Zand and Shakiba, (2013) showed that the effect of N rates (40, 80 and 120 kg/ha) was not significant on the NTPP of sorghum.

The highest NTPP of elephant grass was recorded at the lowest plant density (widest plant spacing) at Holetta and Debre Zeit. This result was coincided with the finding of Yasin *et al*. (2003) who reported that when appropriate spacing exists for each elephant grass, there is capacity to increase the NTPP with the different spacing being attributed to the inconstant nutritional areas and access to light. The result of the present study was also in lined with the reports of other studies by Melkie (2005) and Genet *et al*. (2017) who reported that the NTPP was increased with wider plant spacing in Bana and Desho grasses, respectively. The reason could be due to the fact that light can penetrate without difficulty to the base of the plant at wider plant spacing, and it may have encouraged a number of tillers developments. Zand and Shakiba (2013) were also confirmed higher tillering in response to low densities in sorghum. The present study showed increasing the NTPP of elephant grass with increasing plant spacing from S4 to S1; hence, significantly higher NTPP in S1 (75 cm x 75 cm) and S2 (100 cm x 50 cm) than S3 (125 cm x 25 cm) and S4 (50 cm x 50 cm). This could be due to the fact that plants with relatively wider plant spacing as compared to narrower spacing produced many fine-stemmed tillers due to reduced competition for space, moisture and nutrients during the growing period as reported by Mukhtar *et al*. (2003); Tessema (2008) and Wijitphan *et al*. (2009). The overall mean value (42.8) of NTPP in this study was higher than (15.2) as reported by Halim *et al.* (2013) in elephant grass varieties planted at a spacing of 100 cm x 50 cm in Malaysia.

5.3.1.3. Plant height

Elephant grass harvesting height (HH) was not attained within the suggested range values of 1.0 m to 1.5 m harvesting height during the establishment year at Holetta. The result of this study in elephant grass was concurred with the earlier findings of Fekede *et al*.

(2005) in Ethiopia and Kariuki *et al.* (2016) in Kenya. It was expected as a result of slow growth rate during the establishment year in the cool highlands. In contrast, in the second year of establishment (year 2), elephant grass was achieved aforementioned recommended elephant grass harvesting height within three months of rainy season in the area. Plant height of elephant grass in this study was not significantly affected by the applications of different nitrogen fertilizer (N) rates. In contrast to the present study, Afzal *et al*. (2012) and Abdi (2014) reported that considerably increased the plant height of sorghum forage in Faisalabad district of Pakistan and Rhodes grass in Gewane district of Ethiopia, respectively with the applications of increasing nitrogen fertilizer rates. This could be due to the differences of soil fertility, soil types, environmental conditions and management practices. The overall mean plant height of elephant grass in the present study was coincided with earlier finding of Fekede *et al.* (2005) in the same study area at Holetta. The recommended harvesting height of elephant grass was reached in both year 1 and year 2 at Debre Zeit. It showed that elephant grass can better genetic expressed its potential comparatively under warmer than cooler environments.

Significantly the highest plant height of elephant grass was recorded in relatively at the narrower plant spacing (higher densities) in both locations (Holetta, Debre Zeit), and during the establishment (year 1) and regrowth (year 2), except in the combined analysis over years and locations. The result of the present study was similar with earlier finding of Zewdenesh (2011) who reported that plant height had the direct relationship with population density. One of the main adaptive responses to light competition in plants is an increase of plant height in grasses (Barre *et al*., 2010). According to Schmitt and Wulff (1993) more plant densities sometimes stimulate higher plant height owing to elongation of internodes. On the other hand, the present study was disagreed with the finding of Tessema (2008) who revealed that plant height of elephant grass was significant and taller in lower densities or wider plant spacing than higher densities. Furthermore, according to Genet *et al.*, 2017 and worku *et al.* (2017), plant density had not significant effect on desho grass height which was disagreed with the present study except in the combined analysis over years and locations. The interaction effect of nitrogen fertilizer and plant spacing was significantly affected on the plant height of elephant grass at Holetta and in year 2. This result was agreed with the report of Mihret *et al*. (2018) who showed that the interaction effect of fertilizer type and plant spacing was affected the plant height of desho grass. This result was also coincided with the finding of Beyadglign (2019) who reported that the interaction effect of inorganic fertilizer, soil type and cultivars was significant on the plant height of Brachiaria grass. In contrast, the present study was disagreed with the findings of Tegegn (2001) and Worku *et al*. (2017) who found that non - significant interaction effect of nitrogen fertilizer and plant spacing on the plant height of *Panicum coloratum* and desho grass (*Pennisetum pedicellatum*), respectively at harvest. These variations could be attributed to the differnces of soil fertility and types, environmental conditions (level of moisture availability and temperature) and management practices.

5.3.1.4. Leaf to stem ratio

The LSR is one of the major criterions in evaluating forage quality for the reason that the higher proportion of leaves compared to stem show a better nutritional quality. Leaf to stem ratio is highly associated with forage quality (Julier *et al*., 2000; Sheaffer *et al.*, 2000; Smart *et al*., 2004). The LSR of elephant grass was significantly greater at higher rates of nitrogen fertilizer applications at Debre Zeit and in year 1. The present result was in lined with the finding of Assaeed (1994) who reported that LSR of fodder oats (*Avena sativa* L.) was increased in response to increase rates of nitrogen fertilizer applications. Similarly, Yossif and Ibrahim (2013) supported that LSR of Rhodes grass was increased by increasing nitrogen fertilizer rates. However, forage harvested at Holetta, in year 2 and in the combined analysis over the years and locations in the present study showed non-significant differences on LSR due to application of different rates of N fertilizer was agreed with the findings of Flores *et al*. (2012). On the other hand, the present study was contrasted with the findings of Tariq *et al.* (2011) who reported that decreasing trends of LSR of millet (*Pennisetum americannum* L.) hybrid in response to increasing nitrogen fertilizer rates. It might be attributed to improvement of plant growth as a result of stem elongation.

The LSR of the present study was significant and higher at wider plant spacing than the narrower spacing at Debre Zeit, in the establishment year and in the combined analysis over years and locations. This result was concurred with the findings of elephant grass planted at 50 cm x 50 cm spacing produced lower value (1.49) of LSR (Taye, 2004) than at wider spacing of 100 cm x 50 cm with a figure (1.91) of LSR (Tessema *et al*., 2003). In contrast, Tessema (2008) reported that non-significant and inconsistent LSR of elephant grass was recorded at plant spacing configurations of 150 cm x 75 cm, 150 cm x 50 cm, 150 cm x 25 cm, 100 cm x 75 cm, 100 cm x 50 cm, 100 cm x 25 cm, 50 cm x 75 cm, 50 cm x 50 cm and 50 cm x 25 cm. The overall mean LSR value (2.04) of the present study was higher than the figures (1.07; 1.02) as reported by Tessema (2008) and Halim *et al.* (2013), respectively in elephant grass. Negasu *at al*. (2020) also reported that the overall mean value (1.15) of brachiaria hybrid mulato II grass was lower than the present study. These variations could be attributed to the differences of agronomic management practices and environmental conditions. Generally, the trend of LSR was increased with increasing plant spacing of elephant grass.

5.3.1.5. Forage dry matter and crude protein yields

Forage DMY is a function of growth parameters, including plant population per unit area, tillering, rate of growth and level of fertilizer application. Furthermore, forage yield is also a function of genetic and environmental factors which play a vital role in plant growth and development. The DMY of elephant grass was significantly increased with successive increasing rates of nitrogen fertilizer (N1 < N2 < N3 < N4). The current study was agreed with the earlier findings of Nemera *et al*. (2016) in hay yields of grasslands and Wijitphan *et al.* (2009) in elephant grass who reported that there were increased

DMY with each increasing in level of nitrogen fertilizer application. Moreover, Nemera *et al*. (2016) has also indicated inorganic fertilizer application results quick responses on productivity of grasslands. Similarly, BenYoussef *et al.* (2019) reported that 30 kg ha^{-1} of of nitrogen fertilizer application intensified the DMY of hairy vetch intercropped with winter triticale grass. The present study was concurred with the findings of other researchers (Polat *et al*., 2007; Worku *et al*. 2017) who found that the overall mean dry matter yields of rangeland forage and desho grass increase with increasing rate of nitrogen fertilizer applications, respectively.

Significantly the highest DMY was recorded in narrower plant spacing (S4) and followed a decreasing trend as the spacing increases. These findings concurred with the reports of other studies (Yasin *et al*., 2003; Berihun, 2005; Tessema, 2008) in elephant grass and (Genet *et al*., 2017; Mihret *et al*., 2018) in Desho grass. The narrower plant spacing of elephant grass might be attributed to greater plant numbers per unit area, where higher plant densities (higher plant population), the greater quantity of DMY produced as compared to wider spacing. Wijitphan *et al*. (2009) was also supported that narrower plant spacing (50 cm x 40 cm) produced higher total DMY than wider plant spacing of elephant grass configurations (50 cm x 100 cm, 50 cm x 80 cm and 50 cm x 60 cm). On the other hand, Mokadem *et al.* (2002) was confirmed that increased row spacing reduced yield of multi cut forage sorghum. The overall mean DMY of elephant grass was higher than the figures (5.66 t/ha) reported by Wijitphan *et al*. (2009) in Thailand and (4.28 t/ha) by Zailan *et al.* (2018) in Malaysia in cultivars of elephant grass spacing (100 cm x 50 cm).

The CPY of elephant grass was varied among nitrogen fertilizer rates and plant spacing treatments, which generally followed a similar trend to the forage yield. Significant CPY of elephant grass in the present study was ranged within the values of 0.39 to 0.57 t/ha as reported by Bizelew *et al.* (2019) in nitrogen fertilizer treatments in the same species of grass at Holetta. At Debre Zeit and over locations, the CPY of elephant grass was also agreed and within the range values (0.73 to 1.15 t/ha) as reported by Bizelew *et al.* (2019). The overall mean CP yields of the present study were coincided with the values (0.50, 1.00 and 0.75 t/ha) as reported by aforementioned author in the same species of grass at Holetta, Debre Zeit and over locations, respectively. The CPY of elephant grass was substantially higher at narrower plant spacing than wider spacing at Holetta, Debre Zeit and over locations. The findings of the present study were also concurred with the reports of Genet *et al*. (2017) and Mihret *et al*. (2018) who indicated that higher CPY of dasho grass was recorded at narrower (10 cm x 50 cm) and intermediate (20 cm x 50 cm) plant spacing than wider (30 cm x 50 cm) spacing. In evaluating forage crops, the CP content should not be used as the only parameter to be regarded; the CPY delineates the overall and actual productivity of forage quality. As elephant grass matured there was a decline in CP content and digestibility whereas the DM yield and detergent fibers increased (Cherney *et al*., 1993; Bizelew *et al.*, 2019). However, the highest CPY was recorded when the grass was young indicating that the decrease in CP content was faster than the increase in DMY with maturity and identifying the right time of harvest optimizes the forage with its quality and dry matter productivity.

5.3.2. Forage chemical composition and in vitro dry matter digestibility

5.3.2.1. Chemical composition

Higher nitrogen fertilizer (N) rates were significantly decreased on the ash contents of elephant grass at Debre Zeit and in the combined analysis over locations. These results were concurred with the finding of Kaplan *et al.* (2016) who reported that three rates of nitrogen fertilizer (100, 200 and 300 kg N/ha) were applied and substantially decreased at higher rates on the ash concentrations of corn silage. These results were also supported by the report of Khan *et al.* (1996) showed that higher rates of nitrogen fertilizer applications reduced oat fodder ash contents.

Plant spacing (S) had no significant effect on the ash contents of elephant grass at Debre Zeit and over locations, except at Holetta. These results were concurred with earlier finding of Tessema (2008) who reported that plant spacing did not show considerable differences on the ash contents of elephant grass. On the contrary, according to Genet *et al*. (2017) plant spacing configurations of 10 cm x 50 cm, 30 cm x 50 cm and 50 cm x 50 cm in desho grass was significant on the ash contents in the central highlands of Ethiopia. These differences might be due to variations in forage species, soil fertility, environmental conditions and management practices.

Nitrogen fertilizer (N) applications affected the crude protein (CP) content of elephant grass forage in which application of higher rate of nitrogen fertilizer resulted in higher CP at Holetta, Debre Zeit and over locations. This result is in line with earlier finding of Carpici *et al*. (2010) in forage maize. The higher CP content with application rates of nitrogen fertilizer could be due to the enhanced amino acid formation and in turn it increased the CP content (Afzal *et al*., 2013). Iptas *et al.* (2002) was also supported that a positive effect of nitrogen fertilizer applications on the CP content of Sorghum – Sudan grass hybrid. In contrast, Hussein *et al.* (2019) reported that CP content of Rhodes grass (*Chloris gayana* kunth) was not significantly increased by application of nitrogen fertilizer, but only slight increase on the CP content was obtained by applying the highest rate of nitrogen (120 kg N/ha) in Sudan.

The CP contents obtained in the present study at Debre Zeit and in the combined analysis over locations were concurred with the findings of other studies (Taye, 2004; McDonald *et al*., 2010) who reported that a decline in CP contents of grasses with narrower plant spacing. This result is also justified with the lower leaf to stem ratio obtained in narrower spacing compared to the wider plant spacing. However, at Holetta the CP content was coincided with the finding of Sanmugapriya and Kalpana (2017) who reported that at the narrower plant spacing (30 cm x 10 cm) had more CP content of the multi cut forage sourghum. On the other hand, Wijitphan *et al.* (2009) reported that non-significant effect of plant spacing (50 cm x 100 cm, 50 cm x 80 cm, 50 cm x 60 cm and 50 cm x 40 cm) on the CP contents of elephant grass, which were disagreed with the present study. The overall mean CP content was within the range figures (5.9-13.8%) reported by Kahindi *et al.* (2007) in elephant grass and Bimrew (2016) in desho grass.

The structural carbohydrates (cell wall) fraction is the main factor influencing the voluntary feed intake and digestibility of forages (Harper and McNeill, 2015). The result of the present study was concurred with the findings of Abdi *et a1*. (2015) in *Panicum maximum* and *Cenchrus ciliaris,* and Mihret *et al.* (2018) in desho grass (*Pennisetum pedicellatum* Trin.) who reported that the NDF content was significantly decreased as the nitrogen fertilizer (N) application rates increased. It could be attributed to the enhanced new shoots and leafiness of the plant, which lower in structural components of plant as a result of nitrogen fertilizer applications. Nitrogen fertilizer decreased considerably the ADF content with no statistical differences among 50, 100 and 150 kg N/ha at Holetta and between 50 and 100 kg N/ha at Debre Zeit. The highest ADF content was recorded in with the lowest rate of N application rate (N1) at Holetta, Debre Zeit and in the combined analysis over locations. This result of the present study was in lined with findings of Magani *et al*. (2010) in *Panicum maximum* and Abdi *et a1*. (2015) in *Panicum maximum* and *Cenchrus ciliaris* who reported that the ADF content was significantly influenced and progressively declined with higher rates of N application. Furthermore, the ADF contents of the present study were within the range values of 40.53 to 46.40% in elephant grass applied at N rates of 0, 100, 200, and 300 kg/ha (Parente *et al*., 2012). The ADL content was significantly decreased with increasing N rates. This result was coincided with the report of Abdi *et al*. (2015) who indicated that the ADL contents of *Cenchrus ciliaris* and *Panicum Maximum* species were significantly decreased with increasing nitrogen fertilizer levels (0, 50 and 100 kg/ha). It could be due to the increased application of nitrogen fertilizer rates promote new shoots and leaves of growth which resulted in low lignin content. On the other hand, the present study was disagreed with the finding of Galindo and Buzetti (2019) who reported that the ADL content of

Mombasa guinea grass was not significantly affected by the application of N rates. These differences might be the variations in soil fertility, environmental conditions, forage species and management practices.

Plant spacing of elephant grass had no significant effect on the NDF, ADF and ADL contents in the present study. The ADF content of elephant grass in the present study was agreed with the finding of Genet *et al.* (2017) who reported that non - significant effect of plant spacing was recorded on the ADF content. On the other hand, the results of the present study were disagreed with the findings of Genet *et al.* (2017) who reported that the NDF and ADL contents were increased considerably with narrower plant spacing. Furthermore, Wijitphan *et al*. (2009) reported that the significant effect of plant spacing (50 cm x 100 cm, 50 cm x 80 cm, 50 cm x 60 cm and 50 cm x 40 cm) on the NDF content of elephant grass with the overall mean value (67.4%); it was also a bit higher than the overall mean value (63.5%) of the present study. The NDF content of elephant grass observed in this study was lower than the average figure (66.2%) of tropical grasses (Barton *et al*., 1976). Based on the category of Singh and Oosting (1992), elephant grass quality could be classified as medium quality, owing to the mean NDF content was within in the range values (45-65). Relatively higher ADL content was recorded at wider plant spacing than narrow spacing in the present study which was in lined with the report of Berihun (2005) who reported that significantly higher ADL content was recorded at wider spacing of elephant grass. On the other hand, Berihun (2005) and Taye (2004) reported that there were greatly increased the ADL contents as the plant spacing decreases from (100 cm x 75 cm) to (75 cm x 50 cm) in Bana grass and from (100 cm x 50 cm) to (50 cm x 50 cm) in elephant grass, respectively. In the present study, the overall mean value of the ADL content was lower than the figure (8.26%; 8.18 %) reported, respectively in elephant grass verities at a spacing of 100 cm x 50 cm in Malaysia (Halim *et al*., 2013) and in Brachiara mulato grass (Mustaring *et al*., 2014). The reason could be related with soil type, environmental condition and management practices of the grass.

The NDF content was significantly different between the interaction effect of nitrogen fertilizer and plant spacing at Holetta and Debre Zeit. This was concurred with the finding of Beyadglign (2019) who reported that the significant interaction effect of cultivars, soil type and fertilizer on the NDF content of Brachiaria grass. On the contrary, the present result was disconcurred with the finding of Mihret *et al*. (2018) who reported that the non - significant interaction effect of fertilizer type and plant spacing on the NDF content of desho grass. Moreover, Genet *et al*. (2017) and Wassie *et al*. (2018) showed that non-significant interaction effects of cultivars, altitudes and harvesting dates of Brachiaria grass ecotypes, and between harvesting age and plant spacing of Desho grass on the NDF contents, respectively. The ADF content was considerably varied between the interaction effect of nitrogen fertilizer and plant spacing at Holetta. This was coincided with the finding of Wassie *et al*. (2018) who reported that significance interaction effect of cultivars, altitudes and harvesting dates of Brachiaria grass ecotypes was recorded on the ADF content. These varations could be due the differences of soil fertility, fertilizer type, environmental conditions and management system where studies were conducted.

5.3.2.2. In vitro dry matter digestibility

The IVDMD of elephant grass in the present study was varied from 63.43 to 67.22%. The result of this study was within the range values (53.00 to 80.00%) of elephant grass dry matter digestibility as reported by other studies (Wijitphan *et al*., 2009; Budiman *et al*., 2012). The critical and acceptable threshold level of IVDMD in feeds is 50% (Owen and Jayasuriya, 1989). According to this recommendation, the IVDMD content obtained in the present study was within the acceptable level. The higher IVDMD of elephant grass were recorded at higher rates of nitrogen fertilizer application (N3 and N4) compared to lower rates (N1 and N2). The ADF contents were also lower in N3 and N4 levels of fertilizer application. Similarly, Budiman *et al.* (2012) was supported that the ADF content was negatively linked with the digestibility of elephant grass cultivars. The result of the present study was coincided with the finding of Cox and Charney (2005) who reported that increased *in vitro* digestibility of corn silage with higher rates of nitrogen fertilizer. Nitrogen fertilizer enhances plant cells for photosynthesis process (Bob, 2011) and increases grass forage DMY; moreover its quality of CP content, feed intake and digestibility (Aderinola, 2007).

The result of the present finding was agreed with the report of Wijitphan *et al*. (2009) who showed that the DM digestibility of elephant grass was not significantly affected by plant spacing. Zailan *et al.* (2018) also found that there was no significant variation in IVDMD values (63 to 66%) of elephant grass observed among the cultivars. However, the digestibility of the present study was lower than the values ranged from 68 to 71% as reported by Manyawu *et al.* (2003) in a spacing of 100 cm x 50 cm in elephant grass and hybrid Pennisetums. However, the present study was coincided with the report of Yasin *et al*. (2003) who stated that digestibility of leaves and stem of Mott elephant grass was higher at narrower plant spacing. On the other hand, Berihun (2005) reported that plant spacing configurations of 75 cm x 50 cm , 75 cm x 75, 100 cm x 50 cm and 100 cm x 75 cm was significantly affected the IVDMD of Bana grass with the maximum and minimum IVDMD was recorded at the wider and narrower spacing, respectively. Low quality grasses which are low in digestibility comprise of high proportions of fiber, which are mostly harder to digest (Lee *et al*., 2017). It could be attributed to high temperature that encourages physiological alterations (increased lignin contents and thicker cell walls) in plants (Kering *et al*., 2011). The IVDMD content was considerably varied between the interaction of nitrogen fertilizer and plant spacing at Holetta. The present finding was concurred with the other study of Wassie *et al*. (2018) who found that significance interaction effect of cultivars, altitudes and harvesting dates of Brachiaria grass ecotypes on the IVDMD. The result of present study was also agreed with the finding of Beyadglign (2019) who reported that the interaction effect of cultivars, soil type and fertilizer was significant on the IVDMD content of Brachiaria grass.

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

The study was conducted with the specific objectives to evaluate the effects of: 1) vetch intercropping and plant spacing, 2) harvesting height and nitrogen fertilization and 3) nitrogen fertilization and spacing on the agronomic performance and nutritional qualities of elephant grass in the central highlands of Ethiopia, represented by Holetta (higher highland) and Debre Zeit (medium highland). The following are the major conclusions drawn based on the findings of the study.

- Vetch intercropping with elephant grass at different inter and intra row plant spacing affected most agronomic traits: dry matter biomass yield and forage quality during the establishment year and regrowths in the second year.
- Location has affected performance of intercropping of vetches with elephant grass: higher forage yield of elephant grass was obtained in the warmer (medium highland) ecology (Debre Zeit) than the cooler (higher highland) areas (Holetta). Vetch intercropping with elephant grass resulted in better dry matter yield in cooler area (like Holetta) than warmer places (Debre Zeit) with a yield advantage of 70.0 and 8.5%, respectively, over the pure stand elephant grass.
- Biomass produced form intercropping brings about improved feed quality. In this study as well, due to the high forage quality of vetch the biomass produced from the intercropped forage was remarkably improved. Therefore, it is concluded that intercropping vetches with elephant grass increased forage quality especially the CP and IVDMD compared to the pure stand elephant grass and the total CPY per hectare.
- In evaluating the effect of harvesting height and application of different rates of nitrogen fertilizer on elephant grass production, elephant grass could not grow to the recommended height of harvest (100 to 150 cm) during the establishment year in the cooler highlands like Holetta at the beginning of the dry season. However, it can grow to the recommended height of harvest in warmer areas like Debre Zeit.

- Elephant grass produced significantly higher dry matter yield when harvested at 100 cm and 150 cm than at 50 cm height in both the locations and years, except during the establishmnet year at Holetta.
- Application of nitrogen fertilizer at 100 kg ha^{-1} in split application has affected the performance of the different agronomic traits studied. It increased plant survival rates, tillerings and leaf to stem ratio of elephant grass with increasing nitrogen fertilizer rates in split application at both the locations and years. These growth characteristics in turn afftected dry matter yield production and forage quality.
- Harvesting height and nitrogen fertilizer application rates have affected forage quality of elephant grass. Nitrogen fertilizer has improved crude protein (CP) content and *in vitro* dry matter digestability (IVDMD) of elephant grass forage. Moreover, it reduces NDF and ADF, and improves the overall nutitional value of elephant grass forage.
- Planting density of elephant grass affected agronomic traits, like survivial rate, tillering, plant height and leaf to stem ratio. Generally, it is concluded that a higher planting density results in better forage productivity.
- This study has ascertained that planting elephant grass at higher planting density (50 cm x 50 cm spacing) with application of nitrogen fertilizer at the rate of 100 to 150 kg ha^{-1} in a split application resulted in higher DMY, CPY, IVDMD and CP contents in both the medium (Debre Zeit) and higher (Holetta) highland agroecologies.

6.2. Recommendations

Based on the findings of the present study, the following recommendations are drawn.

- Vetch intercropping at a seed rate of 25 kg ha^{-1} after three weeks of elephant grass establishment at a spacing pattern of 50 cm x 50 cm could result in higher annual forage productivity with improved forage quality in terms of CP content, IVDMD and *in sacco* DM degradability.
- Vetch intercropping has the advantage to offset the slow growth and low forage productivity of elephant grass during the establishment year in the cooler highlands

like Holetta. In warmer areas like Debre Zeit, there are other alternative annual forage legumes like lablab that need to be evaluated in the future.

- To achieve an optimum dry matter production of good quality forage from elephant grass, it has to be harvested at the height of 100 cm to 150 cm. However, in cooler areas where there is slow growth rate, intercropping fast growing forage legumes has the advantage of producing more forages and improving soil fertility.
- For higher productivity (dry matter forage and crude protein yields) and good quality forage (crude protein content and *in vitro* dry matter digestibility) elephant grass planting at higher densities (50 cm x 50 cm) with application of nitrogen fertilizer at the rate of 100 kg/ha in split applications is recommended. Despite the feasibility of applying fertilizer rates (such as 100 kg N/ha) there is a need to further assess the same based on targeted production system and practices. Furthermore, studies on fertilizer requirements and application rates need to be based on soil fertility test results.
- These findings and recommendations are based on rain fed production system. In view of its high potential and wider use as fodder, the different agronomic practices, including plant spacing, fertilizer application, harvesting height and intercropping with forage legumes should be evaluated under irrigation schemes and wider environments.
- Future research needs also to focus on management practice to minimize environmental stresses like frost and drought. In countries like Ethiopia, especially where elephant grass is usually produced under rain fed conditions under stresses of extreme temperature and low soil moisture, designing appropriate conservation practices is very essential. Feeding strategies and level of supplementation are deemed important aspects of future research emphasis.

7. REFERENCES

Abdi H. (2014): Effect of Nitrogen Fertilizer Application on Agronomic traits, Biomass yield and nutritive Value of *Cenchrus Ciliaris* and *Panicum maximum* grown Under Irrigation at Gode, Somali Region. An MSc Thesis Submitted to Haramaya University, Haramaya, Ethiopia, 66p.

Abdi H., Tessema Z., Mengistu U. and Sisay F. (2015): Effect of Nitrogen Fertilizer Application on *in sacco* Rumen Degradability and *in vitro* Dry Matter Digestibility of *Cenchrus Ciliaris* and *Panicum Maximum* Grown under Irrigation. *Global Journal of Medical Research: L Nutrition and Food Science,* **15**(1):6-14.

Adane K. and Berhan T. (2007): Effect of harvesting stage and nutrient levels on nutritive values of natural pasture in central highlands of Ethiopia. *Agricultura Tropica et Subtropic*a, **40**(1):7-12.

Aderinola A. (2007): Herbage Production and Utilization of *Andropogon tectorum* as influenced by fertilizer application and legume intercrop. Ph.D. Dissertation, Department of Animal Production Health, Ladoke Akintola University Technology, Ogbomoso, 157p.

Adesogan A. T., Salawu M. B. and Deaville E. (2002): The effect on voluntary feed intake, in vivo digestibility and nitrogen balance in sheep of feeding grass silage or pea-wheat intercrops differing in pea to wheat ratio and maturity. *Animal Feed Science and Technology*, **96**:161-173.

Adugna T., Getnet A., Diriba G., Lema G. and Alemayehu M. (2012): Feed Resources Availability and Quality. In: Tolera A., Yami A. and Alemu D. (eds.). Livestock Feed Resources in Ethiopia: Challenges, opportunities and the need for transformation, Image Enterprise PLC, Addis Ababa, Ethiopia. 132p.

Adugna T. and Sundstøl F. (1999): Morphological fractions of maize stover harvested at different stages of grain maturity and nutritive value of different fractions of the stover. *Animal Feed Science and Technology*, **81**: 1-16.

Adugna T. and Sundstøl F. (2001): Prediction of feed intake, digestibility and growth rate of sheep fed basal diets of maize stover supplemented with *Desmodium intortum* hay from dry matter degradability of diets. *Livestock Production Science*, **68**:13-23.

Afzal M., Ahmad A. and Ahmad A.U. H. (2012): Effect of nitrogen on growth and yield of sorghum forage (sorghum bicolor (L.) moench cv.) under three cuttings system. University of Agriculture, Faisalabad. *Pakistan Journal of Cercetari Agronomice in Moldora*, XLV (4/152):57-64.

Afzal M.A., Ahmad U.H., Zamir S.I., Khalid F., Mohsin A.U. and Gillani S.M.W. (2013): Performance of multicut forage sorghum under various sowing methods and nitrogen application rates. *J. Anim. Plant Sci*., **23**(1): 232-239.

Akman H., Tamkoc A. and Topal A. (2013): Effects on yield, yellow berry and black point disease of fertilization applications in Hungarian vetch and durum wheat intercropping system. Digital Proceeding of the ICOEST'2013, Cappadocia, June, 18-21, Nevsehir, Turkey, Pp839-847.

Alalade J.A., Akingbade A.A., Akinlade J.A., Akanbi W.B., Gbadamosi J., Okeniyi G., Ajibade A.O. and Akanji K.A. (2014): Herbage yield and nutritive quality of panicum maximum intercropped with different legumes. *International Journal of Science, Environment and Technology*, **3**(1): 224 – 232.

Albayrak S., Turk M., Yuksel O. and Yilmaz M. (2011): Forage yield and the quality of perennial legume-grass mixtures under rain fed conditions. *Not Bot Hort Agrobot Cluj*. **39**:114-118.

Alemayehu M. (1985): Feed resource in Ethiopia. In: Proceedings of a Workshop on Animal Feed Source for Small Scale Livestock Producers, 11-15 November 1985, Nairobi, Kenya.

Alemayehu M. (1998): The Borana and the 1991-92 Drought: A Rangeland and Livestock Resource Study, Institute of Sustainable Development, Addis Ababa, Ethiopia, 102p.

Alemayehu M. (2004): Participatory innovation and research lesson for livestock development. In: Proceedings of the 12th Conference of the Ethiopian Society of Animals Production (ESAP), August 12-14, 2004, Addis Ababa, Ethiopia, Pp 251-259.

Alemayehu M. (2006): Country pasture/forage resource profiles, Pp5-32.

Alemayehu M. and Getnet A. (2012): The Evolution of Forage Seed Production in Ethiopia. Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia, Pp15-32.

Alemayehu M., Gezahagn K., Fekede F. and Getnet A. (2017): Review on Major Feed Resources in Ethiopia: Conditions, Challenges and Opportunities. *J. Agr. Sci. and Res*., **5**(3):176-185.

Alemayehu M., Gezahagn K., Getnet A. and Fekede F. (2016): Improved forage crops production strategies in Ethiopia: A review. *Academic Research Journal of Science and Research*, **4**(6): 285-296.

Ameri A. A. and Jafari A. A. (2016): Effects of Mixed and Row Intercropping on Yield and Quality Traits of Alfalfa and Three Grass Species in Rain fed Areas of Northern Khorasan, Iran. *Journal of Rangeland Science*, **6**(4):377-387.

Anderson W.F., Dien B.S., Brandon S.K. and Peterson J.D. (2008): Assessment of Bermuda grass and bunch grasses as feed stocks for conversion to ethanol. *Applied Biochemistry and Biotechnology*, **145**: 13-21.

Anil L., Park R.H.P. and Miller F.A. (1998): Temperate intercropping of cereal for forage: a review of the potential for growth and utilization with particular reference to the UK. *Grass and Forage Sciences,* **53**: 301-317.

Ansah T., Osafo E.L.K. and Hansen H.H. (2010): Herbage yield and chemical composition of four varieties of elephant (*Pennisetum purpureum*) grass harvested at three different days after planting. *Agriculture and Biology Journal of North America*, **1**(5):923-929.

AOAC (Association of Official Analytical Chemists) (1990): Official Methods of Analysis. 15thed. AOAC, Arlington, VA.

AOAC (1995): Official Methods of Analysis. Pp5-13. (16th ed.), Association of Official Analytical Chemists, Washington, DC.

Arshad M. U., Maqsood A. and Amir S.R. (2010): Effect of nitrogen fertilization and harvesting intervals on the yield and forage quality of elephant grass (*Pennisetum purpureum*) under mesic climate of pothowar plateau. *Pakistan Journal of Agriculture Sciences*, **47**(3):231-234.

Assaeed A.M. (1994): Yield Response of Forage Oats (*Avena sativa* L.) to Nitrogen Fertilization Harvested at Successive Stages of Maturity. *Alex. J. Agric. Res.,* **39** (3): 159-170.

Aumont G. and Salas M. (1996): Effect of stage of maturity, cultivar, nitrate fertilization, soil type on mineral content of sugarcane. *J. Agric. Univ. P. R., Rio Piedras: Agricultural Experiment Station*, **80**: 37–46.

Baloyi J.J., Ngongoni N.T. and Hamudikuwanda H. (2008): Chemical composition and ruminal degradability of Cowpea and Silverleaf desmodium forage legumes harvested at different stages of maturity. *Tropical and Subtropical Agroecosysttems*, **8**:81-91.

Bamikole M. A., Akinsoyinu A. O., Ezenwa I., Babayemi O. J., Akinlade J. and Adewumi M. K. (2004): Effect of six-weekly harvests on the yield, chemical composition and dry matter degradability of *Panicum maximum* and *Stylosanthes hamata* in Nigeria. *Grass and Forage Science*, **59**:357–363

Banik P., Midya A., Sarkar B. and Ghosh S.S. (2006): Wheat and chickpea intercropping systems in an additive series experiment: advantages and weed smothering. *Europ. J. Agron*., **24**: 325-332.

Barre P., Gueye B. and Gastal F. (2010): Effect of light quality and quantity on leaf growth in *Lolium perenne* L. In Sustainable Use of Genetic Diversity in Forage and

Turf breeding, Proceedings of the EUCARPIA 2009, La Rochelle, France, 11–14 May 2009; Huyghe, C., Ed.; Springer: Berlin, Germany, Pp61–65.

Barton F.E., Amos H.E., Burdick D. and Wilson R. L. (1976): Relationship of chemical analysis to *in vitro* digestibility for selected tropical and temperate grasses. *J. Ani, Sci.,* **43**(2): 504-512.

Bedir S. (2010): Research on determination of proper seed mixture ratio of Hungarian vetch and barley to be grown under conditions of Karaman. An MSc Thesis Submitted to Cukurova University, Adana, Turkey.

Belachew Z., Yisehak K., Taye T. and Janssens G.P.J. (2013): Chemical composition and *in sacco* ruminal degradation of tropical trees rich in condensed tannins. *Czech J.Anim. Sci.*, **58**(4):176-192.

BenYoussef S., Salma S. K., Sourour A., Bilal S., Jamila I. and Hichen B. S. (2019): Effect of Different Levels of Nitrogen Fertilization on Forage Yields and Quality of Hairy Vetch (*Vicia villosa*, Roth) Triticale (Xtritcosecale, Witmack) Mixtures. *The Open Agriculture Journal*, **13**:90-100.

Berihun M. (2005): Effect of planting patterns and harvesting days on yield and quality of Bana grass [*Pennisetum Purpureum* (L.) x *Pennisetum Americanum* (L.)]. MSc Thesis Sumbitted to Haramaya University, Haramaya, Ethiopia, 93p.

Beyadglign H. (2019): Effects of fertilizer and soil types on different cultivars of brachiaria species biomass yield and quality and farmers' perception in West Gojam Zone, Ethiopia. MSc Thesis Submitted to Bahir Dar University, Bahir Dar, Ethiopia, 137p.

Bilal M.Q., Saeed M. and Sarwar M. (2002): Effect of varying levels of nitrogen and FYM application on tillering and height of Mott grass. *International Journal of Agriculture and Biology*, **2**(1-2): 21-23.

Bimrew A. (2016): Evaluation of the Agronomic, Utilization, Nutritive and Feeding Value of *Desho* Grass (*Pennisetum pedicellatum).* PhD Dissertation Presented to the School of Graduate Studies of Jimma University, Jimma, Ethiopia, 127p.

Bizelew G. (2012): Assessment of livestock feed resources, seasonal chemical composition and *in sacco* dry matter degradability of major forage species in Abobo woreda, Gambella Regional State, Ethiopia. MSc Thesis Submitted to Hawassa University, Hawassa, Ethiopia, 140p.

Bizelew G., Berhan T., Getnet A. and Fekede F. (2019): Effect of Harvesting Height and Nitrogen Fertilization on Herbage Yield and Nutritional Qualities of Elephant Grass in the Central Highlands of Ethiopia. *Global Veterinaria*, **21**(5): 287-297.

Bizelew G., Berhan T., Getnet A. and Fekede F. (2020): Effects of Spacing of Elephant Grass and Vetch Intercropping on Agronomic Performance and Herbage Yield of Elephant Grass. *Ethiop. J. Agric. Sci*., **30**(2): 13-30.

Bob M. (2011): The good, bad and interesting roles of nitrogen and nitrogen fertilizers in home lawn care- part 2 of a 3-part series on understanding and using home lawn fertilizers. University of Minnesota Cooperative Extension.

Boonman J.G. (1997): Farmers' success with tropical grasses: Crop/pastures rotation in mixed farming in East Africa. Ministry of Foreign Affairs, The Hague, Netherlands.

Bovolenta S., Spanghero M., Dovier S., Orlandi D. and Clemenentel F. (2008): Chemical composition and net energy content of alpine pasture species during the grazing season. *Animal Feed Science and Technology*, **146**: 178-191.

Bremner J. and Mulvaney C. (1982): Nitrogen-total in: Page, al ed. Methods of soil analysis. Part 2: Chemical and microbiological properties, 595–624. Am. Soc. Agron., Madison, WI, USA.

Budiman B., Soetrisno R.D., Budhil S.P.S. and Indrianto A. (2012): Morphological characteristics, productivity and quality of three elephant grass (*Pennisetum purpureum* Schum) cultivars harvested at different ages. *J. Indonesian Trop. Anim. Agric*., **37**(4): 294–301.

Caballero R. and Goicoechea E.L. (1995): Forage yield quality of common vetch and oat sown varing seeding ratios and seeding rates of vetch. *Field Crops Research*, **41**: 135-140.

Camacho L.M., Rojoa R., Salem A.Z.M., Provenza F.D., Mendoza G.D., Avilés F. and M ontanez-Valdez O.D. (2010): Effect of season on chemical composition and *in situ* degradability in cows and in adapted and unadapted goats of three Mexican Browse Species. *Animal Feed Science Technology*, **155**:206-212.

Campos F.P., Sarmento P., Nussio L.G., Lugão S.M.B., Lima C.G. and Daniel J.L.P. (2013): Fiber monosaccharides and digestibility of Milenio grass under N fertilization. *Animal Feed Science and Technology*, **183**: 17–21.

Cardinale B. J., Wright J. P., Cadotte, M. W., Carroll I. T., Hector, A., Srivastava D. S., Loreau M., Weis J.J (2007): Impacts of plant diversity on biomass production increase through time because of species complementarity. Proceedings of the National Academy of Sciences of the United States of America, **104**(46):18123-18128.

Carpici B., Celic N. and Bayram G. (2010): Yield and quality of forage maize influenced by plant density and nitrogen rate. *Turkish J. Field Crops*, **15**(2):128-132.

Casler M.D. and Jung H.J.G. (2006): Relationships of fibre, lignin, and phenolics to *in vitro* fibre digestibility in three perennial grasses. *Animal Feed Science Technology*, **125**:151- 161.

Chanthakhoun V., Wanapat M. and Berg J. (2012): Level of crude protein in concentrate supplements influenced rumen characteristics, microbial protein synthesis and digestibility in swamp buffaloes (*Bubalus bubalis*). Livestock Science 144: 197–204. Composition and *in vitro* digestibility of continuously grazed star grass. *Anima l Feed Science and Technology*, **113**: 239-249.

Chen S. B. (1995): Neway Excell: An excel application program for processing feed degradability data. International Feed Resources Unit, Rowett Research Institute, Aberdeen, UK.

Cherney D.J.R., Cherney J.H. and Lucey R.F. (1993): *In-vitro* digestion Kinetics and quality of perennial grass as influenced by forage maturity. *J. Dairy Sci.* **76**:790-797.

Clavero L.T. (1997): Tiller dynamics of dwarf elephant grass (*Pennisetum purpureum* cv. Mott) under defoliation. In: Proceedings of the XVIII International Grassland Congress, Winnipeg and Saskatoon, Canada, 1997, Session 22, Pp31–32.

Coll L.A., Cerrudo R., Rizzalli J., Monzon P. and Andrade F.H. (2012): Capture and use of water and radiation in summer intercrops in the southeast Pampas of Argentina. *Field Crops Research,* **134**: 105-113.

Cook B. G., Pengelly B. C., Brown S. D., Donnelly J. L., Eagles D. A., Franco M. A., Hanson J., Mullen B. F., Partridge I. J., Peters M. and Schultze-Kraft R. (2005): *Tropical forages*. CSIRO, DPI and F (Qld), CIAT and ILRI, Brisbane, Australia, Pp120 -125.

Corre-Hellou G., Dibet A., Hauggaard-Nielsen H., Crozat Y., Gooding M., Ambus P., Dahlmann C., von Fragstein P., Pristeri A., Monti M. and Jensen E.S. (2011): The competitive ability of pea-barley intercrops against weeds and the interactions with crop productivity and soil N availability. *Field Crops Res*., **122**:264–272.

Cox W. J., Cherney J. H., Cherney D. J. R. and Pardee R. D. (1994): Forage quality and harvest index of corn hybrids under different growing conditions. *Agronomy Journal*, **86**:277–282.

Cox W.J. and Charney D.J.R. (2005): Row spacing, plant density, and nitrogen effects on corn silage. *Agron. J.,* **93**: 597–602.

CSA (Central Statistical Agency) (2018): Agricultural Sample Survey. Report on livestock and livestock characteristics (Private peasant holdings), volume II, Statistical Bulletin, 587. Addis Ababa, Ethiopia, 100p.

Dangi S., Devkota N.R. and Barsila S. R. (2018): Productivity and chemical composition of oat-legumes mixtures, and legume monoculture in southern subtropical plains, nepal. Agriculture and Forestry University, Rampur, Chitwan, Nepal. *Journal of Agriculture and Forestry University*, **2**: 191-198.

Daniel K. (1996): Effects of nitrogen application and stage of development on yield and nutritional value of Rhodes Grass (*Chloris gayana*). *Ethiopian Journal of Agricultural Science*, **15**: 86-101.

Depeters E. (1993): Forage quality and its implications. In: California Alfalfa workshop (eds) proceedings of the 23rd California alfalfa symposium at fresno, California, USA, Pp: 93-146.

Dereje F., Seyoum B. and Zenash S. (2010): Characterizing and predicting chemical composition and *in vitro* digestibility of crop residue using near infrared reflectance spectroscopy (NIRS). *Livestock Research for Rural Development,* **22***(*29). Retrieved on June 21, 2018, from http://www.lrrd.org/lrrd22/ 2 feka22029.htm.

Deribe G., Addisu J. and Shewangizew W. (2017): Biomass Yield and Nutritive Value of Ten Elephant Grass (*Pennisetum purpureum*) Accessions at Areka, Southern Ethiopia. *World Journal of Agricultural Sciences*, **13**(5): 185-190.

Dhanoa M.S. (1988): On the analysis of Dacron bag data for low degradability feeds. *Grass Forages Science,* **43**: 441-444.

Dhima K.V., Lithourgidis A.S. Vasilakoglou I.B. and Dordas C.A. (2007): Competition indices of common vetch and cereal intercrops in two seeding ratio. *Field Crops Research*, **100**:249-256.

Diriba G. (2014): Agronomic and Nutritional Evaluation of Selected Forage Legumes and Locally Available Feedstuff, and Characterization of Forage and Dairy Innovation Systems in Bako and Nekemte Peri-Urban Areas, Oromia, Ethiopia. PhD Dissertation Submitted to Addis Ababa University, College of Veterinary Med icine and Agriculture, Bishoftu, Ethiopia, 187p.

EARO (Ethiopian Agricultural Resrarch Organization) (2000): Livestock Research Strate gy Summary. Livestock Research Directorate, Ethiopian Agricultural Research Org anization, Addis Ababa, Ethiopia, 133p.

EARO (2004): Directory of released crop varieties and their management. Addis Ababa, Ethiopia.

Ergon A., Kirwan L., Fystro G., Bleken M. A., Collins R. P. and Rognli O. A. (2016): Species interactions in a grassland mixture under low nitrogen fertilization and two cutting frequencies. II. Nutritional quality. *Grass Forage Sci.,* **72**:333–342.

Eskandari H. (2012): Intercropping of maize (*Zea mays*) with cowpea (*Vigna sinensis*) and mungbean (*Vigna radiata*): effect of complementarity of intercrop components on resource consumption, dry matter productionand legumes forage quality. *Journal of Basic and Applied Scientific Research*, **2**: 355-360.

Eskandari H. and Kazemi K. (2011): Weed control in maize-cowpea intercropping system related to environmental resources consumption. *Notulae Scientia Biologicae*, **3**: 57-60.

Eskandari H., Ghanbari A. and Javanmard A. (2009a): Intercropping of cereals and legumes for forage production. *Notulae Botanicae Horti. Agrobotanici Cluj-Napoca*, **1**(1):07-13.

Eskandari H., Ghanbari-Bonjar A., Galavai M. and Salari M. (2009b): Forage quality of cow pea (*Vigna sinensis*) intercropped with corn (*Zea mays*) as affected by nutrient uptake and light interception. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, **37(1)**: 171-174.

FAO (Food and Agriculture Organization). (2015): Grassland Index. A searchable catalogue of grass and forage legumes. FAO, Rome, Italy.

Farrell G., Simons S. A. and Hillocks R. J. (2002.): Pests, diseases and weeds of Napier grass, *Pennisetum purpureum*: a review. *Journal of pest management*, **48**(1): 39-48.

Farzi R., Gholami M., Baninasab B. and Gheysari M. (2017): Evaluation of different mulch materials for reducing soil surface evaporation in semi-arid region. *Soil Use and Management***, 33**: 120–128.

Fekede F. (2004): Evaluation of potential forage production qualities of selected oats (*Avena sativa* L.) genotypes. An MSc Thesis Presented to School Graduate Alemaya University of Agriculture, Alemaya, Ethiopia.

Fekede F., Getnet A., Lulseged G., Muluneh M. and Tadesse T. (2005): Evaluation of Napier grass-vetch mixture to improve herbage yield in the central highlands of Ethiopia. In: Proceeding of 13th Conference of Ethiopia Society of Animal Production (ESAP), August 25 – 27, 2004, Pp155-163; Addis Ababa, Ethiopia.

Fekede F., Shiv P., Getnet A., Seyoum B., Getu K., Aemiro K. and Gezahegne K. (2014): Dynamics in nutritional characteristics of natural pasture hay as affected by harvesting stage, storage method and storage duration in the cooler tropical high lands. *African Journal of Agricultural Research*, **9**(43): 3233-3244.

Ferreira E. A., Abreu J. G., Martinez J. C., Braz T.G.S. and Ferreira D. P. (2018): Cutting ages of elephant grass for chopped hay production. *Agropec. Trop., Goiânia*, **48** (3):245-253.

Flores R. A., Urquiaga S., Alves B. J. R., Collier L. S. and Boddey R.M. (2012): Yield and quality of elephant grass biomass produced in the Cerrados region for bioenergy. *Eng. Agríc., Jaboticabal*, **32**(5):831-839.

Foster A., Vera C.L., Malhi S.S. and Clarke F.R. (2014): Forage yield of simple and complex grass legume mixtures under two management strategies. *Canadian Journal of Plant Science*, **94**: 41-50.

Francis C. A. (1989): Biological efficiencies in multiple cropping systems. *Advance in Agronomy*, **42**:1-42.

Francis J. K. (2004): Elephant grass (*Pennisetum purpureum* Schumacher). In: Francis, J.K. (Ed.). Wildland shrub of the United States and its Territories: thamnic descriptions: volume 1. Gen. Tech. Rep. IITF-GTR-26. USDA Forest Service, *International Institute of Tropical Forestry*, 830p.

Galindo F. S. and Buzetti. S (2019): Rates and sources of nitrogen fertilizer application on yield and quality of *Panicum maximum* cv. Mombasa, *IDESIA (Chile)*, **37**(2): 67-73.

Galindo F.S., Buzetti S., Filho M.C. M. T., Dupas E. and Ludkiewicz M. G. Z. (2017): Application of different nitrogen doses to increase nitrogen efficiency in Mombasa guinegrass (*Panicum maximum* cv. mombasa) at dry and rainy seasons. *Australian Journal of Crop Sciences (AJCS)*, **11**(12):1657-1664.

Gebreegziabher Z. and Tsegay L. (2016): Status of improved forage production, utilization and constraints for adoption in Wolaita Zone, Southern Ethiopia. *Livestock Research for Rural Development*, **28**(78). Retrieved on June 2, 2 020, from http://www.lrrd.org/lrrd28/5/zere28078.htm

Gebreyohannes B., Eik L.O. and Adugna T. (2006): Chemical composition and in vitro gas production of vetch (*Vicia sativa*) and some browse and grass species in northern Ethiopia. *African Journal of Range and Forage Science*, **23**(1): 69-75.

Gee G.W. and Bauder J.W. (1986): Particle Size Analysis. Methods of Soil Analysis. Part 1. Physical and Mineralogical Methods. 2nd Edition. Agronomy No: 9. 383-411, 1188p, Madison, Wisconsin USA.

Genet T., Bimrew A. and Yeshambel M. (2017): Effects of harvesting age and spacing on plant characteristics, chemical composition and yield of desho grass (*Pennisetum pedicellatum Trin*.) in the highlands of Ethiopia. *Tropical Grasslands-Forrajes Tropicales,* **5**(2):77–84.

Geren H. and Kavut Y. T. (2015): Effect of different plant densities on the yield and some silage quality characteristics of giant king grass (*Pennisetum hybridum*) under mediterranean climatic conditions. *Turkish Journal of Field Crops,* **20**(1): 85-91.

Getachew G., Makkar H.P.S. and Becker K. (2006): Tropical browses: contents of phenolic compounds, in vitro gas production and stoichiometric relationship between short chain fatty acid and in vitro gas production. *J Agric Sci*., **139**:341–352.

Getnet A. (1999): Feed resources assessment and evaluation of forage yield, quality and intake of oats and vetches grown in pure stands and in mixture in the highlands of Ethiopia. An MSc Thesis, Swedish University of Agricultural Sciences, Department of Animal Nutrition and Management. Uppsala, Sweden, 83p.

Getnet A. (2007): Evaluation of Tagasaste (*Chamaecytisus Palmensis*) as forage for ruminants. A PhD dissertation, Humboldt University of Berlin, Germany, Pp75-100.

Getnet A. and Gezahagn K. (2012): Seed Research and Development of Perennial Forage Crops in the Central Highlands. In: Getnet Assefa, Mesfin Dejene, Jean Hanson, Getachew Anemut, Solomon Mengistu & Alemayehu Mengistu (eds.). Forage Seed Research and Development in Ethiopia. Proceedings of workshop held on 12- 14 May, 2011 at EIAR, Addis Ababa, Ethiopia. ISBN: 978-99944-53-84-9.

Getnet A. and Ledin I. (2001): Effect of variety, soil type and fertilizer on the establishment, growth, forage yield and voluntary intake by cattle of oats and vetches cultivated in pure and stands and mixtures. *Animal feed science and technology*, **92(1):** 95-111.

Getnet A., Peters K.J., Kijora C. and Muluneh M. (2012): Field Performance of Tagasaste (*Chamaecytisus palmensis*) Under Different Harvesting Management in a Tropical Highland Area of Ethiopia. *Ethiopian Journal of Agricultural Sciences,* **22**:143-158.

Getnet A., Solomon M., Fekede F. and Seyoum B. (2016): Animal Feed Resources Research in Ethiopia: Achievements, Challenges and Future Directions. *Ethiopian Journal of Agricultural Sciences*, Pp141-155.

Getnet A., Sonder K., Winkc M., Kijora C., Steinmueller N. and Peters K.J. (2008): Effect of variety and harvesting management on the concentration of tannins and alkaloids in tagasaste. *Animal Feed Science and Technology*, **144**: 242–256.

Gezahagn K., Fekede F., Getnet A., Mengistu A., Alemayehu M., Aemiro K., Kassahun M., Solomon M., Estifanos T., Shewangizaw W. and Mergia A. (2017): Agronomic performance, dry matter yield stability and herbage quality of elephant grass (*Pennisetum purpureum (L.)* Schumach) accessions in different agro-ecological zones of Ethiopia. *Journal of Agricultural and Crop Research,* **5**(4): 49-65.

Gezahagn K., Fekede F., Getnet A., Mengistu A., Alemayehu M., Aemiro K., Kassahun M., Solomon M., Estifanos T., Shewangizaw W. and Mergia A. (2016): Evaluation of elephant grass (*Pennisetum purpureum (L.)* Schumach) Accessions for Agronomic Traits under Different Environmental Conditions of Ethiopia. *International Journal of Advanced Research,* **4**(4): 1029-1035.

Gezahagn K., Getnet A., Alemayehu M. and Fekede F. (2014): Forage nutritive values of vetch species and their accessions grown under nitosol and vertisol conditions in the central highlands of Ethiopia. *Livestock Research for Rural Development*, **26(***20).* Retrieved on December 24, 2015, from http://www.lrrd.org/lrrd26/1/kebe26020.htm.

Ghanbari A. and Lee H.C. (2003): Intercropped field beans (*Vicia faba*) and wheat (*Triticum aestivum*) for whole crop forage: effect of nitrogen on forage yield and quality. *The Journal of Agricultural Science*, **138**: 311-314.

Girjesh G.K. and Patil V.C. (1991): Weed management studies in groundnut and sunflower intercropping system. *Journal of Oilseeds Research*, **8**: 7-13.

Gulwa U., Mgujulwa N. and Beyene S.T. (2018): Review on Benefits of grass-legume inter-cropping in livestock systems. *African Journal of Agricultural Research*, **13** (26):1311-1319.

Gulwa U., Mgujulwa N. and Beyene S.T. (2017): Effect of Grass-legume Intercropping on Dry Matter Yield and Nutritive Value of Pastures in the Eastern Cape Province, South Africa. *Universal Journal of Agricultural Research*, **5**(6): 355-362.

Gunduz E.T. (2010): Effects of mixture ratio on hay yield and hay quality of Hungarian vetch+wheat mixture under Diyarbakir conditions. An MSc Thesis, Cukurova University, Adana, Turkey. (In Turkish with English abstracts).

Gwayumba W., Christensen D.A., McKinnon J.J. and Yu P. (2002): Dry matter intake, digestibility and milk yield by Friesian cows fed two Napier grass varieties. *Asian*-Australasian *Journal of Animal Science*, **15**(4): 516-521.

Halim R.A., Shampazuraini S. and Idris A.B. (2013): Yield and nutritive quality of nine elephant grass varieties in Malaysia. *Malaysian Journal of Animal Science*, **16** (2):37–44.

Hanna W.W., Chaparro C.J., Mathews B.W., Burns J.C., Sollenberger L.E. and Carpenter J.R. (2004): Perennial pennisetums. In: Moser LE, Burson BL, Sollenberger LE, eds. Warm-season (C4) grasses. *Madison, American Society of Agronomy: Monograph series*, **34**: 503–535.

Hare M.D., Gruben I.E., Tatsopong P., Lunpha A., Saengkham M. and Wangpicher K. (2004): Inter-row planting of legumes to improve and create protein concentration in *Paspalum abatum* cv. Ubon pastures in north-east Thailand. *Tropical Grasslands*, **38**: 167-177.

Harper J. K. and McNeill D. M. (2015): The role iNDF in the regulation of feed intake and the importance of its assessment in subtropical ruminant systems (the role of iNDF) in the regulation of forage intake. *Agriculture*, **5**:778-790.

Harris K., Anderson W. and Malik R. (2010): Genetic relationships among elephant grass (*Pennisetum purpureum* Schum.) nursery accessions using AFLP markers. Plant Genetic Resource, **8**: 63–70.

Havilah E.J. (2011): Forage and Pasture: *Annual forage and pasture crops–establishment and management*. *Elsevier:* 563–575.

Havlin J.L., Beaton J.D., Tisdale S.L.and Nelson W.L. (1999): Soil fertility and fertilizers: An introduction to nutrient management 6th edition. Pearson Education, Inc., India.

Hay R.K. and Walker A. J. (1989): Introduction to the physiology of crop yield. Longman Group UK Limited, Harlow, UK, 292p.

Hazary M.E.H., Bilkis T., Khandaker Z.H., Akbar M.A. and Khaleduzzaman A.B.M. (2015): Effect of nitrogen and phosphorus fertilizer on yield and nutritional quality of Jumbo Grass (Sorghum Grass × Sudan Grass). *Advances in Animal and Veterinary Sciences,* **3**(8): 444-450.

Hendershot W.H., Lalande H. and Duquette M. (1993): Soil reaction and exchangeable acidity. In: Carter M.R. (Ed.), Soil Sampling and Methods of Analysis, Pp141-145. Canadian Society of Soil Science, Lewis Publishers, Ann Arbor, MI.

Hernandez M., Argel P.J., Ibrahim M.A. and Mannetje, L.'t. (1995): Pasture production, diet selection and live weight gains of cattle grazing *Brachiaria brizantha* with or without *Arachis pintoi* at two stocking rates in the Atlantic Zone of Costa Rica. *Tropical Grasslands*, **29**: 134-141.

Humphreys L.R. (1994): Tropical Forages: Their role in sustainable agriculture. Australia: The University of Queens land, 430p.

Hussein H. A. M., Dagash Y. M. I. and Mohammed M. I. (2019): Effect of Nitrogen and Variety on Quality Performance of Rhodes Grass (*Chloris gayana* kunth) in the Sudan. *Global Journal of Science Frontier Research: D Agriculture and Veterinary*, **19**(6): 33-40.

Iannetta P.P., Young M., Bachinger J., Bergkvist G., Doltra J., and Lopez-Bellido R.J. (2016): A comparative nitrogen balance and productivity analysis of legume and non-legume supported cropping systems: the potential role of biological nitrogen fixation. *Frontiers in Plant Science*, 7:1700. doi: 10.3389/fpls. 2016. 01700.

ILRI (International Livestock Research Institute) (2010): Elephant grass ILRI 14984 (*Pennisetum purpureum*) for livestock feed on small-scale farms. Information leaf let on livestock feeds and feeding technologies for small-scale farmers. Fodder Adoption Project fodder adoption.wordpress.com.

ILRI (2013): Getting superior Napier grass to dairyfarmers in East Africa. Elephant Grass Stunt and Smut Project **-** http://bit.ly/Qfts3v**.** International Livestock Research Institute - www.ilri.org/foragediversity.

Iptas S. and Brohi A.R. (2002): Effect of nitrogen rates and methods of nitrogen application on dry matter yield and some characters of Sorghum – Sudan grass hybrid. Acta Agriculturae Scandinavica, Section-B. *Soil & Plant Sci.*, **52**: 96-100.

Ishii Y., Yamaguchi N. and Idota S. (2005): Dry matter production and *in vitro* dry matter digestibility of tillers among elephant grass (*Pennisetum purpureum* Schumach) varieties. *Japanese Journal of Grassland Science*, **51**:153–163.

Islam M.R., Saha C.K., Sarker N.R., Jalil M.A and Hasanuzzaman M. (2003): Effect of variety on proportion of botanical fractions and nutritive value of different elephant grass (*Pennisetum purpureum*) and relationship between botanical fractions and nutritive value. *Asian*- Australasian *Journal of Animal Science*, **16**(6): 837-842.

Johansen M., Lund P. and Weisbjerg M.R. (2018): Feed intake and milk production in dairy cows fed different grass and legume species: a meta-analysis. *Animal*, **12**(1): 66–75.

Jorgensen S.T, Pookpakdi A., Tudsri S., Stolen O., Ortiz R. and Christiansen J.L. (2010): Cultivar-by-cutting height interactions in elephant grass (*Pennisetum purpureum* Schumach) grown in a tropical rain fed environment. *Acta Agriculturae Scandinavi ca*, **60**:199–210.

Jukenvicius S. and Sabiene N. (2007): The content of mineral elements in some grasses and legumes. *Ekologija*, **53**:44-52.

Julier B., Huyghe C. and Ecalle C. (2000): Within and among-cultivar genetic variation in alfalfa. *Crop Science*, **40**: 365-369.

Jusoh S., Alimon A.R. and Kamiri M.S. (2014): Agronomic properties, dry matter production and nutritive quality of guinea grass (*Megathrysus maximus*) harvested at different cutting intervals. *Malaysian Journal of Animal Sciences*, **17**(2): 31-36.

Kabuga J.D. and Darko, C.A. (1993): *In sacco* degradation of dry matter and nitrogen in oven dried and fresh tropical grasses and some relationships to *in vitro* dry matter digestibility. *Animal Feed Science and Technology*, **40**: 191-205.

Kahindi R.K., Abdulrazak S.A. and Muinga R.W. (2007): Effect of supplementing Napier grass

Kammes K. L. and Allen M. S. (2012): Rates of particle size reduction and passage are faster for legume compared with cool-season grass, resulting in lower rumen fill and less effective fiber. *J. Dairy Sci*., **95**:3288–3297.

Kaplan M., Baran O., Unlukara A., Kale H., Arslan M., Kara K., Beyzi S. B., Konca Y. and Ulas A. (2016): The Effects of Different Nitrogen Doses and Irrigation Levels on Yield, Nutritive Value, Fermentation and Gas Production of Corn Silage. *Turk J Field Crops*, **21**(1):100-108.

Kandel R., Singh H.P., Singh B.P., Harris-Shultz K.R. and Anderson W.F. (2016): Assessment of genetic diversity in elephant grass (*Pennisetum purpureum* Schum.) using microsatellite, single-nucleotide polymorphism and insertion-deletion markers from Pearl Millet (*Pennisetum glaucum* (L.) R. Br.). *Plant Mol. Biol. Rep*., **34**: 265–272.

Karagic D., Mikic A. Milosevic B., Vasiljevic S. and Dusanic N. (2012): Common vetch-wheat intercropping: Haylage yield and quality depending on sowing rates. *African Journal of Biotechnology,* **11**:7637–7642.

Kariuki I.W., Mwendia S.W., Muyekho F.N., Ajanga S.I. and Omayio D.O. (2016): Biomass production and forage quality of head-smut disease Resistant elephant grass accession. *African Crop Science Journal,* **24:**157– 165.

Kariuki J.N. (1998): The potential of improving elephant grass under smallholder dairy farmers' conditions in Kenya. A PhD Dissertation Submitted to Wageningen Agricultural University, Wageningen, Netherlands, 197p.

Keba H. T., Madakadze I. C., Angassa A. and Hassen A. (2013): Nutritive value of grasses in semi-arid rangelands of Ethiopia: Local experience based herbage preference evaluation versus laboratory analysis. *Asian-Australasian Journal of Animal Sciences*, **26**: 366-377.

Kering M.K., Guretzky J., Funderburg E. and Mosali J. (2011): Effect of nitrogen fertilizer rate and harvest season on forage yield, quality, and macronutrient concentrations in midland Bermuda grass. *Commun Soil Sci Plant Anal,* **42**:1958–1971.

Kesang W., Krishna R., Harilal N., Thuk T., Chhoyten D. and Durba M. (2015): Forage growth, yield and quality responses of elephant hybrid grass cultivars to three cutting intervals in the Himalayan foothills. *Tropical Grasslands – Forrajes Tropicales,* **3***: 142−150.*

Khaleduzzaman A.B.M., Islam N., Khandaker Z.H. and Akbar M.A. (2007): Effect of different doses of Nitrogen and phosphorus fertilizer on yield and quality of elephant grass (*Pennisetum purpureum*). *Bangladesh Journal of Animal Sciences*, **36**(1-2): 41-49.

Khan M.J., Shahjalal M. and Sarker A.R. (1996): Yield, chemical composition and nutritive value of oat fodder at different levels of nitrogen fertilization. *Bangladesh Journal of Animal Sciences*, **25**(1-2): 109-115.

Kizima J.B., Mtengeti E. J. and Nchimbi Msolla S. (2014): Seed yield and vegetation cha racteristics of *Cenchrus ciliaris* as influenced by fertilizer levels, row spacing, and cutting height and season. *Livestock Research for Rural Development Volume,*

26 (148): Retrieved August 2, 2020, from http://www.lrrd.org/lrrd26/8/kizi26148.htm.

Klopfenstein T. J., Mass R. A., Creighton K. W. and Patterson H. H. (2001): Estimating forage protein degradation in the rumen. *Journal of Animal Science, Supplement*, **79**: E208 – E217.

Koc A., Erkovan S., Erkovan H.I., Oz U., Birben M.M. and Tunc R. (2013): Competitive effects of plant species under different sowing ratios in some annual cereal and legume mixtures. *Journal of Animal and Veterinary Advances*, **12**(4):509-520.

Kuoppala K., Ahvenjarvi S., Rinne M. and Vanhatalo A. (2009): Effects of feeding grass or red clover silage cut at two maturity stages in dairy cows. 2. Dry matter intake and cell wall digestion kinetics. *J. Dairy Sci*., **92**:5634–5644.

Kusewa P.K, Wanjala B.M., Kamau R.I. and Kamau J.N. (1980): Growing Banagrass with legume. Agricultural Research Station Kitale Annual Report 1979, Pp49 - 52.

LDMPS (Livestock development master plan study) (2006): Livestock development master plan study. Phase 1. Addis Ababa, Ethiopia.

Lee H.S. and Lee I.D. (2000): Effect of nitrogen fertilizer levels on the dry matter yield, quality and botanical composition in eight-species mixtures. *Korean Journal of Animal Sciences*, **42**: 727-734.

Lee M.A., Davis A.P., Chagunda M.G.G. and Manning P. (2017): Forage quality declines with rising temperatures, with implications for livestock production and methane emissions. *Bio geosciences*, **14**:1403–1417.

Lemerle D., Causens R.D., Gill L.S., Peltzer S.J., Moerkerk M., Murphy C.E., Collins D. and Cullis B.R. (2004): Reliability of higher seeding rates of wheat for increased competitiveness with weeds in low rainfall environment. *Journal of Agriculture Science*, **142**:395- 409.

Lemerle D., Verbeek B. and Diffey S. (2006): Influence of field pea (*Pisum sativum*) density on grain yield and competitiveness with annual rye grass (*Lolim rigidum*) in south-eastern Australia. *Australian Journal of Experimental Agriculture*, **46**: 1465-1472.

Li L., Tilman D., Lambers H. and Zhang F-S. (2014): Biodiversity and overyielding: insights from below-ground facilitation of intercropping in agriculture. *New Phytologist*, **203**: 63–69.

Lithourgidis A.S., Dordas C.A., Damalas C.A. and Vlachostergios D.N. (2011): Annual intercrops: An alternative pathway for sustainable agriculture. *Australian Journal of Crop Science*, **5**:396-410.

Longo C., Hummel J., Liebich J., Bueno I.C.S., Burauel P., Ambrosano E.J., Abdalla A.L., Anele U.Y. and Sudekum K.H. (2012): Chemical characterization and in vitro biological activity of four tropical legumes, *Styzolobium aterrimum*, *Styzolobium deeringianum*, *Leucaena leucocephala*, and *Mimosa caesalpiniaefolia*, as compared with a tropical grass Cynodon spp. for the use in ruminant diets. *Czech Journal of Animal Science,* **57**(6): 255–264.

Lounglawan P., Lounglawan W. and Suksombat W. (2014): Effect of cutting interval and cutting height on yield and chemical composition of King elephant grass (*Pennisetum purpureum x Pennisetum americanum*). APCBEE Procedia, **8**: 27–31.

Lukuyu B., Gachuiri C.K., Lukuyu M.N., Lusweti C. and Mwendia S. (2012): Feeding dairy cattle in East Africa. East Africa Dairy Development Project, Nairobi, Kenya.

Magani I.E. and Okwori A.I. (2010): Effect of nitrogen sources and harvesting four grass species in Southern Guinea Savanna of Nigeria. *Research Journal of Animal and Veterinary Sciences*, **5**:23-30.

Mahala A. G., Nsahlai I. V., Basha N. A. D. and Mohammed L. A. (2009): Nutritive evaluation of natural pasture at early and late rainfall season in Kordofan and Butana, Sudan. *Australian Journal of Basic and Applied Sciences*, **3**: 4327-4332.

Mahapatra S.C. (2011): Study of grass-legume intercropping system in terms of competition indices and monetary advantage index under acid lateritic soil of India. *American Journal of Experimental Agriculture*, **1**(1): 1-6.

Malik R. (2010): The introduction of grain legume crops or legume-rich pastures provided N to a subsequent cereal or oilseed crops: In proceedings of the 19th World Congress of Soil Science, Soil Solutions for a Changing World. Australia.

Manyawu J. G., Chakoma C., Sibanda S., Mutisi C. and Chakoma I. C. (2003): The effect of harvesting interval on herbage yield and nutritive value of Elephant grass and hybrid pennisetums. *Asian- Aust. J. Anim. Sci.*, **16**(7):996-1002.

Mariotte P., Buttler A., Johnson D., Thebault A. and Vandenberghe C. (2012): Exclusion of root competition increases competitive abilities of subordinate plant species through root-shoot intecactions. *Journal of Vegetable Science*, **23**:1148-1158.

Matusso J.M.M., Mugwe J.N. and Mucheru-Muna M. (2014): Potential Role of Cereal-Legume Intercropping Systems in Integrated Soil Fertility Management in Smallholder Farming Systems of Sub-Saharan Africa. *Research Journal of Agriculture and Environmental Management*, **3**(3): 162-174.

May A., Souza V. F., Gravina G. A. and Fernandes P. G. (2016): Plant population and row spacing on biomass sorghum yield performance. *Crop Production*, **46**(3):434-439.

Mazaheri D., Madani A. and Oveysi M. (2006): Assessing the land equivalent ratio (LER) of two corn (*Zea mays* L.) varieties intercropping at various nitrogen levels in Karaj, Iran. *Journal of Central European Agriculture*, **7**(2): 359-364.

McDonald P., Edwards R.A., Greenhalgh J.D. and Morgan C.A. (2002): Animal Nutrition (7th edn). Long man group. United Kingdom Ltd, England, Pp607-693.

McDonald P., Edwards R.A., Greenhalgh J.F.D and Morgan C.A (2010): Animal Nutrition 7th ed. Longman Group UK Ltd, England, 693p.

McDowell L.R. (2003): Minerals in Animal and Human nutrition, 2nd ed., Amsterdam. The Netherlands, Elsevier, Pp660.

McDowell L.R. and Valle G. (2000): Major minerals in forages. In: D.I. Givens, E. Owen, R.F.E. Axford and H. M. Omed (eds.). Forage Evaluation in Ruminant Nutrition. CABI Publishing, New York, NY, Pp373-397.

McKenzie F.R., Jacobs J.L. and Ward G.N. (2006): Irrigated dairy pasture yield and water use efficiency responses to summer applied nitrogen. *Proc NZ Grassland Assn*, **68**: 155-160.

Midega C.A.O., Khan Z.R., Amudavi D.M., Pittchar J. and Pickett J.A. (2010): Integrated management of *Striga hermonthica* and cereal stemborers in finger millet (*Eleusine coracana* (L.) Gaertn.), through intercropping with *Desmodium int ortum*. *International Journal of Pest Management*, **56**:145–151.

Mimila Zemene (2018): Effect of Plant Spacing and Harvesting Age on Plant Characteristics, Yield and Chemical Composition of Brachairia Mutica Grass at Bahir Dar, Ethiopia. An MSc. Thesis Submitted to Bahir Dar University College of Agriculture and Environmental sciences,112p.

Minson D.J. (1990): Forage in ruminant nutrition, Academic Press, Inc., California.

Mohammadi K.S.Y., Heidari G.K.S., Majidi M. (2012): Effective factor on Biological Nitrogen Fixation. *African Journal of Agricultural Research*, **7**(12):1782-1788.

Mokadem S.A., Taha E.M., El-Geddawy I.H. and Bekheet M.A. (2002): Response of spring sugarcane to some row spacing and intercropping with sorghum and soybean. *Egyptian J. Agric*. Res., **78**: 197–214.

Moreira F. B., Prado I. N., Cecato U., Wada F. Y. and Mizubuti I. Y. (2004): Forage evaluation, chemical composition and in-vitro digestibility of continuously grazed star grass. *Animal Feed Science and Technology*, **113**: 239-249.

Muhammad A. U., Maqsood A. and Amir S. R. (2010): Effect of nitrogen fertilization and harvesting intervals on the yield and forage quality of elephant grass (*Pennisetum purpureum)* under mesic climate of pothowar plateau. *Pakistan* Journal of *Agricultural* Sciences, **47***(3): 231-234.*

Mhlanga B., Cheesman S., Maasdorp B., Mupangwa W. and Thierfelder C. (2015): Contribution of Cover Crops to the Productivity of Maize-Based Conservation Agriculture Systems in Zimbabwe. *Crop Science*, **55**: 1791–1805.

Muia J.M.K, Tamminga S., Mbugua P.N. and Kariuki J.N. *(*2000): Optimal stage of maturity for feeding elephant grass *(Pennisetum purpurem)* to dairy cows in Kenya. *Tropical Grasslands*, **33**: 182-190.

Mujeeb-ur-Rahman, Muhammad I., Muhammad S.J. and Kashif W. (2007): Effect of different plant spacing on the production of cauliflower (*Brassica oleracae* var. Botrytis*)* under agro climatic conditions of DI Khan. *Pakistan Journal of Biological Sciences*, **10**: 4531-4534.

Mukhtar M., Ishii Y., Tudsri S., Idota S. and Sonoda T. (2003): Dry matter productivity and overwintering ability of dwarf and normal elephant grass as affected by planting density and cutting frequency. *Plant Production Science,* **6**:65–73.

Muluye F. (2019): Improved Forage Production in Ethiopia: Utilization, Challenges and Prospects for Adoption: A Review. *Journal of Biology, Agriculture and Healthcare*, **9**(21):5-11.

Mupangwa W. and Thierfelder C. (2014): Intensification of conservation agriculture systems for increased livestock feed and maize production in Zimbabwe. *International Journal of Agricultural Sustainability*, **12**: 425–439.

Mushtaque M., Ishaque M., Haji M. A. A. and Bakhsh A. (2010): Influence of maturity on morphological characters and biomass of buffel grass. *Pakistan Journal of Science*, **62**(2):124-127.

Mustaring I., Soebarinoto S. and Marsetyo Y. (2014): Growth, Yield and Nutritive Value of New Introduced Brachiaria Species and Legume Herbs as Ruminant Feed in Central Sulawesi, Indonesia. *Pakistan J. Agric. Res*. **27**(2):89-98.

Mutegi J.K., Mugendi D.K., Verchot L. and Kungu J.B. (2008): Combining elephant grass with leguminous shrubs in contour hedgerows controls soil erosion without competing with crops. *Agroforestry Systems*, **74**: 37-49.

Mwangi D.M., Cadisch G., Thorpe W. and Giller K.E. (2004): Harvesting management options for legumes inter-cropped in Elephant grass in the central highlands of Kenya. *Tropical Grasslands*, **38**: 234-244.

Mwendia S. W., Wanyoike M., Nguguna J.G.M., Wahome R.G. and Mwangi D. M. (2006): Evaluation of Napier grass cultivars for resistance to elephant head smut. Proceedings of the 10th KARI Biennial Scientific Conference, KARI, Nairobi, Kenya, Pp85-97.

Nadeem M., Ansar M., Anwar A., Hussain A. and Khan S. (2010): Performance of winter cereal-legumes fodder mixtures and their pure stand at different growth stages under rain fed conditions of pothowar. *Journal of Agricultural Research*, **48**(2):181-192.

Naroon W., Kenneth W. and Moore G. (2006): Forage Quality of Native Warm-Season grasses in Response to Nitrogen Fertilization and Harvest Date.

Negash D., Getachew A., Mengistu U. and Solomon M. (2017): Chemical Composition and Nutritive Value of Oats (*Avena sativa*) Grown in Mixture with Vetch (*Vicia villosa*) with or Without Phosphorus Fertilization in East shoa Zone, Ethiopia. *Acad. Res. J. Agri. Sci. Res.*, **5**(7):471-479.

Negasu Y., Yeshambel M. and Bimrew A. (2020): Effects of Fertilizer Types and Plant Spacings on Plant Morphology, Biomass Yield and Chemical Composition of Brachiaria Hybrid Mulato II Grass Grown in Lowlands of Northwest Ethiopia. *Animal Science and Biotechnologies*, **53**(1):20-35.

Nemera F., Zewdu T.K. and Ebro A. (2016): Effect of organic and inorganic fertilizer application on improvement of degraded grazing land in the central highland of Ethiopia. *Livestock Research for Rural Development, 29 (59).* Retrieved March 17, 2020, from http://www.lrrd.org/lrrd29/3/tess29059.html.

Nguku S. A., Njarui D. N., Musimba N. K.R., Amwata D. and Kaindi E.M. (2016): Primary Production Variables of Brachiaria Grass Cultivars in Kenya Dry lands, Tropical and Subtropical. *Agro ecosystems*, **19**(1): 29-39.

Ngwira A.R., Aune J.B. and Mkwinda S. (2012): On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in Malawi. *Field Crops Research*, **132**: 149–157.

Njoka-Njiru E. N., Njarui M. G., Abdulrazak S. A. and Mureithi J. G. (2006): Effect of intercropping herbaceous legumes with elephant grass on dry matter yield and nutritive value ofthe feedstuffs in semi-arid regions of eastern Kenya. *Agricultura Tropica et Subtropica*, **39**(4): 255-267.

Norton B.W. and Poppi D.P. (1995): Composition and nutritional attributes of pasture legumes. In: D'Mello, J.P.F. and Devendra, C. (eds). Tropical legumes in animal nutrition (CAB International: Wallingford, UK), Pp23–47.

Nyambati E.M., Muyekho F.N., Onginjo E. and Lusweti C.M. (2010): Production, characterization and nutritional quality of elephant grass (*Pennisetum purpureum* Schum.) cultivars in Western Kenya. *African Journal of Plant Science*, **4**:496–502.

Nyambati E.M., Sollenberger L.E. and Kunkle W.E. (2003): Feed intake and lactation pe rformance of dairy cows offered elephant grass supplemented with legume hay. *Live stock Production Science*, **83**: 179-189.

Obok E.E., AkenOva M. E. and Iwo G. A. (2012): Forage potentials of interspecific hybrids between elephant grass selections and cultivated pearl millet genotypes of Nigerian origin. *Journal of Plant Breeding and Crop Sciences*, **4**(9): 136 – 143.

Ofori F. and Stern W.R. (1987): Cereal-legume intercropping system. *Advance in Agronomy*, **41**: 41-90.

Ojo V.O.A., Dele T.A., Amole U.Y., Adeoye S.A., Hassan J.A.O. and Idowu O.J. (2013): Effect of intercropping *Panicum maximum* var. Ntchisi and *Lablab purpureus* on the growth, yield and chemical composition of *Panicum maximum* var. Ntchisi at different harvesting times. *Pakistan Journal of Biological Sciences*, **16**(22): 1605-1608.

Okeagu M.U. (1991): The Agronomy of newly introduced grass pastures in the northern Guinea Savanna Zone of Nigeria. 3. *Panicum maximum* (Jacq). *World Review of animal production*, **26**(1): 87-90.

Okwori A.I. and Magani I.E. (2010): Influence of nitrogen sources and cutting interval on the digestibility of four grass species in the southern guinea savanna of Nigeria. *Agriculture and Biology Journal of North America*, **1**: 526-533.

Oliveira V.S., Morais J.A.S., Muniz E.N., Fagundes J.L., Lima I.G.S., Santana J.S. and Santos C.B. (2017): Ruminal kinetics of tropical forages submitted or not to irrigation. *Boletim de Indústria Animal*, **74**: 195-204.

Olsen S.R. and Sommers L.E. (1982): Phosphorus. In: Page A.L., Miller R.H. and Keeney D.R. (Eds.) Chemical and microbiological properties. 2nd edition, American Society of Agronomy, Madison, Wisconsin, Pp 403-427.

Onyeonagu C.C. (2005): Reclamation of a run-down pasture through improved management. An MSc Thesis Submitted to the Faculty of Agriculture University of Nigeria, 65p.

Onyeonagu C.C. and Asiegbu J.E. (2012): Influence of cutting frequency and Fertilizer-N application on tiller production and herbage yield distribution over time in a guinea grass (*Panicum maximum*) sown pasture. *African Journal of Biotechnology*, **11**:7170–7185.

Orodho A.B. (2006): The role and importance of Napier grass in the smallholder dairy industry in Kenya. http://www.fao.org/ag/AGP/AGPC/doc/Newpub/napier/napier_kenya.htm

Orskov E.R. (1998): Feed evaluation with emphasis on fibrous roughages and fluctuating supply of nutrients: a review. *Small Ruminant Research*, **28**:1–8.

Orskov E.R. (2000): The *in situ* technique for the estimation of forage degradability. In: D.I. Givens, E. Owen, R.F.E. Axford and H.M. Omed (Editors), Forage Evaluation in Ruminant Nutrition. CABI Publishing, Wallingford, UK, Pp175-188.

Orskov E.R. and McDonald I. (1979): The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. *J. Agri. Sci.*, **88**: 645-650.

Osuji P. O., Nsahlai I. V. and Khalili H. (1993): Feed evaluation. ILCA Manual 5 ILCA (International Livestock Center for Africa), Addis Ababa, Ethiopia.

Owen E. and Jayasuriya M.C.N. (1989): Use of crop residues as animal feeds in developing countries: a review. *Research and Development in Agriculture*, **6**(3):129- 138.

Ozel A. (2010): Determining the appropriate mixture rations in barley + Hungarian vetch and barley + common vetch mixtures. An MSc. Thesis. Mustafa Kemal University, Hatay, Turkey (in Turkish with English abstract).

Pandey S. and Sinha B.K. (2006): Plant physiology, 4 editions. Vikas Publishing House Pvt. L., Newdelhi, India.

Pascual J.J, Fernandez C., Diaz J. R., Garces C. and Rubert-Aleman J. (2000): Voluntary intake and *in vivo* digestibility of different date-palm fractions by Murciano-Granadina *(Capra Hircus*). *Journal of Arid Environments*, **45**: 183-189.

Peters M., Horne P. and Schmidt A. (2001): The role of forages in reducing poverty and degradation of natural resources in tropical production systems. London: Agricultural Research & Extension Network (AgREN), 12p. (Agricultural Research & Extension Network Paper 117).

Pinar I. (2007): The effect of different rates of mixture on the yield and some yield characteristics of hairy vetch (*Vicia villosa* Roth.) + barley (*Hordeum vulgare* L.) and hungarian vetch (*Vicia pannonica* Crantz.) + barley (*Hordeum vulgare* L.) mixtures. M.Sc. Thesis. Ege University. Izmir, Turkey.

Polat T., Bukun B. and Okant M. (2007): Dose response effect of nitrogen and phosphorus on forage quality, yield and economic return of rangelands. *Pakistan Journal Botany*, **39**: 807-816.

Preissel S., Reckling M., Schlafke N. and Zander P. (2015): Magnitude and farm economic value of grain legume pre-crop benefits in Europe: a review. *Field Crops Research*, **175**: 64–79.

Premaratne S. and Premalal G. G.C. (2006): Hybrid elephant (*Pennisetum perpureum* X *Pennisetum americarnum*) Var. CO-3: A resourceful Fodder Grass for Dairy Development in Sri Lanka. *The Journal of Agricultural Sciences*, **2**(1): 22–33.

Qin A.Z., Huang G.B., Chai Q., Yu A.Z. and Huang P. (2013): Grain yield and soil respiratory response to intercropping systems on arid land. *Field Crops Res*., **144**:1–10.

Rahman M. H., Rahman M. M., Bari M. S., Islam M. R. and Quraishy M. A. (2016): Varietal Performance of Elephant Fodder (*Pennisetum purpureum*) Influenced by Nitrogen Fertilizer under Mango Based Agroforestry System. *International Journal of Plant & Soil Science*, **13**(2): 1-6.

Ramadhan A., Njunie M. N. and Lewa K. K. (2015): Effect of Planting Material and Variety on Productivity and Survival of Elephant Grass (*Pennisetum purpureum* schumach) in the Coastal Lowlands of Kenya. *East African Agricultural and Forestry Journal*, **81**(1): 40-45.

Rambau M.D., Fushai F. and Baloyi J.J. (2016): Productivity, chemical composition and ruminal degradability of irrigated elephant grass leaves harvested at three stages of maturity. *South African Journal of Animal Science*, **46**(4): 398-408.

Ratnadass A., Fernandes P., Avelino J. and Habib R. (2012): Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: a review. *Agron Sustain Dev*., **32**:273–303.

Rao S.C., Northup B.K., Philips W.A. and Mayeux H.S. (2007): Inter-seeding novel cool-season annual legumes to improve Bermuda grass paddocks. *Crop Sciences*, **47**(1): 168-173.

Resende A. S., Xavier R. P., Quesada D. M., Urquiaga S., Alves B. J. R. and Boddey R. M. (2003): Use of green manures in increase inputs of biological nitrogen fixation to sugar cane. *Biology and Fertility of Soils*, **37**:215-220.

Ribeiro Junior G.O., Velasco F.O., Faria Júnior W.G., Teixeira A.M., Machado F.S., Magalhaes F.A., Jayme D.G. and Gonçalves L.C. (2014): In situ degradation kinetic of Andropogon Gayanus grass silages harvested at three stages of maturity. *Braz. J. Vet. & Anim. Sci.*, **66**(6):1883-1890.

Rotili P., Gnocchi G., Scotti C. and Kertikova D. (2001): Breeding of the alfalfa plant morphology for quality. In: Proceedings of the XIV Eucarpia Medicago sp. Group Meeting. *Zaragoza*, **45**: 25-28.

Rusinamhodzi L., Corbeels M., Nyamangara J. and Giller K.E. (2012): Maize–grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in central Mozambique. *Field Crops Research*, **136**: 12–22.

Saeed M., Siddiqui N.A., Maqsood M. and Mahmood T. (1996): Effect of nitrogen and plant spacing on growth, green fodder yield and quality of Mott Elephant grass (*Pennisetum purpureum*). *Pakistan Journal of Science and Industrial Research*, **39** **(**1-4): 54-59.

Salamone A.M., AbuGhazaleh A.A. and Stuemke C. (2012): The effects of maturity and preservation method on nutrient composition and digestibility of master graze. *J. Anim. Res. & Tech*., **1**(1):13-19.

Samuel M., Mesfin D. and Solomon A. (2015): Dry Matter Yield and Agronomic Performance of Herbaceous Legumes Intercropped with Elephant Grass

(*Pennisetum purpureum*) in the Semi-Arid Areas of Eastern Amhara Region. *International Journal of Recent Research in Life Sciences* (IJRRLS), **2**(1):7-14.

Sanh M.V., Wiktorsson H. and Ly L.V. (2002): Effects of natural grass forage to concentrate ratios and feeding principles on milk production and performance of crossbred lactating cows. *Asian- Australian Journal of Animal Sciences*, **15**(5): 650-657.

Sanmugapriya L. and Kalpana R. (2017): Evaluation of Spacing and Fertilizer Doses for Multicut Forage Sorghum under Irrigated Condition. *Chem Sci Rev Lett.*, **6**(24): 2190-2194.

Sarwar M., Nisa M., Khan M. A. and Mushtaque M. (2006): Chemical Composition, Herbage Yield, and Nutritive Value of Panicum antidotale and Pennisetum orientale for Nili Buffaloes at Different Clipping Intervals. *Asian- Australasian Journal of animal science*, **19**(2): 176-180.

SAS (Statistical Analysis System) (2002): SAS Institute Inc., Version 9.1, Cary, NC, USA.

Sayar M.S. (2014): Determination of forage yield performance and the possibilities at entering crop rotation system for some annual forage legumes species in ecological conditions of Çınar district. *Dicle University Journal of Institute of Natural an Applied Science*, **3**(1):19-28.

Schmitt J. and Wulff R.D. (1993): Light spectral quality, photochromic and plant competition. *Trends Ecol. Evol.*, **8:47**–51.

Seyoum B. (1995): Evaluation of nutritive values of herbaceous legumes, browse species and oil seed cakes using chemical analysis. In vitro digestibility and nylon bag technique. An MSc Thesis Submitted Alemaya (Haramaya) University of Agriculture, Ethiopia, 209p.

Seyoum B. and Zinashi S., Tadesse T.T. and Liyusew A. (1998): Evaluation of Elephant (*Pennisetum purpureum*) and Pennisetum hybrids (*Pennisetum purpureum* x *pennisetum typhoides*) in the central highlands of Ethiopia. Proceedings of the 5th National Conference of the Ethiopian Society of Animal Production (ESAP), May 14-17, 1997. Addis Ababa, Ethiopia, Pp194-202.

Sheaffer C.C., Martin N.P., Lamb J.F.S., Cuomo G.R., Jewett J.G. and Quering S.R. (2000): Leaf and stem properties of alfalfa entries. *Agronomy Journal*, **92**: 733-739.

Siam H.S., Abd-El-Kader G.M., El-Alia H.I. (2008): Yield and yield components of maize as affected by different sources and application rates of nitrogen fertilizer. *Res. J. Agric. Biol. Sci*., **4**(5): 399-412.

Silva L.F.P., Cassoli L.D., Roma Junior L.C., Rodrigues A.C.O. and Machado P.F. (2008): *In situ* degradability of corn stover and Elephant grass harvested at four stages of maturity. *Sci. Agri.*, **65:**595-603.

Silveira M.L., Vendramini J.M.B., Sellers B., Monteiro F.A., Artur A.G. and Dupas E. (2015): Bahia grass response and N loss from selected N fertilized sources. *Grass and Forage Science,* **70**: 154-160.

Singh G.P. and Oosting S.J. (1992): A model for describing the energy value of straws. *Indian Dairyman*, **44**: 322-327.

Smart A.J., Schacht W.H., Moser L.E. and Volesky J.D. (2004): Prediction of leaf/stem ratio using near-infrared reflectance spectroscopy (NIRS): A Technical Note. In: *Agronomy & Horticulture Faculty Publications*, **96**:316–318.

Snijders P.J.M., Kariuki J.N., Orodho A.B., Kiura J.N. and Mogaka L.M. (1992): Effect of nitrogen fertilizer and cutting stage on yield and quality of elephant grass (*Pennisetum purpureum*). KARI, NDDP, NAHRC, Naivasha, Kenya,46p.

Solomon B., Solomon M. and Alemu Y. (2008): Influence of rainfall pattern on grass/legume composition and nutritive value of natural pasture in Bale Highlands of Ethiopia. Livestock Research for Rural Development. Volume 20, Article #38. (Accessed 20 September, 2020, from http://www.lrrd.org/lrrd20/3/boga 20038.htm).

Soares J.P.G.; Berchielli T.T.; Aroeira L.J.M.; Deresz F.; Verneque R.S. (2004.): Chromium oxide technique for intake estimates of chopped elephant grass (*Pennisetum purpureum* Schum.) using lactating cows. *Revista Brasileira de Zootecnia*, **33**: 811-820.

Stapleton J. (2016): Unlocking the potential of Ethiopia's livestock sector: growth, jobs and environmental sustainability.In"https://news.ilri.org/2020/06/04/unlocking the potential- of-the-Livestock-Sector-Ethiopia/".

Starks P.J., Zhao D., Philips W.A. and Coleman S.W. (2006): Herbage mass, nutritive value and canopy spectral reflectance of Bermuda grass. *Grass Forage Sci.*, **61**:101-111.

Sturludottir E., Brophy C., Elanger G.B., Gustavsson A.M., Jørgensen M., Lunnan T. and Helgadotti A. (2013): Benefits of mixing grasses and legumes for herbage yield and nutritive value in Northern Europe and Canada. *Grass and Forage Science*, **69**(2):229-240.

Styler L.L., Satter L.D. and Dinius D.A. (1979): Effect of ruminal ammonia concentration on nitrogen utilization by steer. *Journal of Animal Science*, **48**: 906.

Sumran W., Pornchai L. and Chutipong A. (2009): Effects of plant spacing on yields and nutritive values of elephant grass (*Pennisetum purpureum* Schum.) under intensive management of nitrogen fertilizer and irrigation. *Pakistan Journal of Nutrition*, **8** (8):1240-1243.

Sun X., Luo N., Longhurst B. and Luo J. (2008): Fertiliser Nitrogen and Factors Affecting Pasture Responses. *The Open Agriculture Journal*, **2**: 35-42.

Susmel P., Stefanon B., Mills C.R. and Spanghero M. (1990): Rumen degradability of organic matter, nitrogen and fiber fractions in forages. *Animal Production*, **51**: 515-536.

Suter M., Hofer D. and Luscher A. (2017): Weed suppression enhanced by increasing functional trait dispersion and resource capture in forage ley mixtures. *Agriculture, Ecosystems and Environment,* **240**: 329–339.

Taleie N., Hamidoghli Y., Rabiei B. and Hamidoghli S. (2012): Effects of plant density and transplanting date on herbage, stevioside, phenol and flavonoid yield of Stevia rebaudiana Bertoni. *International Journal of Agriculture and Crop Sciences,* **4**(6): 298-302.

Tariq M., Ayub M., Elahi M., Ahmad A.H., Chaudhary M.N. and Nadeem M.A. (2011): Forage yield and some quality attributes of millet (*Pennisetum americannum* L.) hybrid under various regimes of nitrogen fertilization and harvesting dates. *Afr. J. Agric. Res.*, **6**(16):3883-3890.

Taye B. (2004): Effects of harvesting day on biomass, nutritive value and dry mater digestibility of elephant grass only or mixing with *Desmodium introtum* or *Fabaceae*. An MSc Thesis submitted to the School of Graduate Studies of Alemaya (Haramaya) University, Alemaya, Ethiopia,70p.

Taye B., Solomon M. and Prasad N. K. (2007): Effects of cutting dates on nutritive value of elephant (*Pennisetum purpureum*) grass planted sole and in association with Desmodium (*Desmodium intortum*) or Lablab (*Lablab purpureus*). *Livestock Research for Rural Development*, **19**(11). Retrieved July 10, 2019, from http://www.lrrd.org/lrrd19/1/bayb19011.htm.

Tefera T. L., Puskur D., Hoekstra D. and Azage T. (2010): Commercializing Dairy and Forage Systems in Ethiopia: An Innovative Systems Perspective.Working paper No. 17, ILRI, Nairobi, Kenya, 57p.

Tegegn G. (2001): Evaluation of *Panicum coloratum* productivity and nutritive value under varying stages of harvest, low levels of N fertilization in association with *Stylosynthesis hamate* at different seed rate proportions during establishment year. MSc. thesis Alemaya University.

Tessema Z. (1999): Elephant grass adapts well in north-western Ethiopia. AgriTopia, quarterly newsletter of the Ethiopian Agricultural Research Organization, 14 (1), January–March 1999.

Tessema Z. (2000): Productivity, Nutritive value and digestibility of Elephant grass (*Pennisetum purpureum*) as influenced by height of harvesting and different sources of fertilizer applications. An M.Sc. thesis presented to School of Alemeya University,110p.

Tessema Z. (2005): Variation in growth, yield, chemical composition and *in vitro* dry matter digestibility of elephant grass accessions (*Pennisetum purpureum*). *Tropical Science*, **45**: 93-99.

Tessema Z. (2008): Effect of plant density on morphological characteristics, yield and chemical composition of elephant grass (*Pennisetum purpureum* (L.) Schumach). *East African Journal of Sciences,* **2**(1): 55-61.

Tessema Z. and Alemayehu M. (2010): Management of elephant Grass (*Pennisetum purpureum* (L.) Schumach) for High Yield and Nutritional Quality in Ethiopia: A Review. *Ethiopian Journal of Animal Production*, **10**(1): 73–94.

Tessema Z. and Baars R.M.T. (2003): Effect of cutting height of elephant grass on rumen degradation and *in vitro* dry matter digestibility. *Tropical Science,* **43**:125-131.

Tessema Z. and Baars R.M.T. (2006): Chemical composition, dry matter production and yield dynamics of tropical grasses mixed with perennial forage legumes. *Tropical Grasslands,* **40:150** –156.

Tessema Z., Baars R.M.T. and Alemu Y. (2003): Effect of plant height at cutting and fertilizer on growth of elephant grass (*Pennisetum purpureum* Schumach.). *Tropical Science,* **43**: 57-61.

Tessema Z., Baars R.M.T., Alemu Y. and Dawit N. (2002a): *In sacco* dry matter and nitrogen degradation and their relationship with *in vitro* dry matter digestibility of elephant grass (*Pennisetum purpureum* Schumach.) as influenced by plant height at cutting. *Australian Journal of Agricultural Research*, **53**: 7-12.

Tessema Z., Baars, R. M. T. and Alemu Y. (2002b): Effect of plant height at cutting, source and level of fertilizer on yield and nutritional quality of elephant grass (*Pennisetum purpureum Schumach*.). *African Journal of Range and Forage Science*, **19**:123–128.

Tessema Z., Mihret J. and Solomon M. (2010): Effect of defoliation frequency and cutting height on growth, dry-matter yield and nutritive value of elephant grass (*Pennisetum purpureum* (L.) Schumach). *Grass and Forage Science*, **65**:421–430.

Tilahun A., Solomon M. and Ralph R. (2005): Intensification of Livestock Feed Production in Ethiopian Highlands: Potential and Experiences of the African Highla nds Initiative1Presented at the 19th EVA Annual conference, 8 June 2005, ECA, Ad dis Ababa. http://www.researchgate.net/publication/265007609

Tilley J. M. A. and Terry R. A. (1963): A two stage technique for the *in vitro* digestion of forage crops. *Journal of British Grassland Society*, **18**: 104-111.

Tremblay G. F., Michaud R. and Bélanger G. (2003): Protein fractions and ruminal undegradable proteins in alfalfa. *Canada Journal of Plant Science,* **83**: 555–559.

Tudsri S., Ishii Y., Numaguchi H. and Prasanpanich S. (2002a): The effect of cutting interval on the growth of *Leucaena leucocephala* and three associated grasses in Thailand. *Tropical Grasslands,* **36**:90–96.

Tudsri S., Jorgensen S.T., Riddach P. and Pookpakdi A. (2002b): Effect of cutting height and dry season date on yield and quality of five elephant grass cultivars in Thailand. *Tropical Grasslands,* **36**: 248-252.

Usman Semman. (2014): Effect of Different Spacing of Elephant Grass (*Pennisetum purpureum*) Intercropped with or without Lablab (*Lablab purpureus*) on Biomass Yield and Nutritional Value of Elephant Grass. An MSc Thesis Submitted to the School of Graduate Studies of Haramaya University, 64p.

Utamy R.F., Ishii Y., Idota S., Harada N. and Fukuyama K. (2011): Adaptability of dwarf elephant grass under cut and carry and grazing sysytems for smallholder beef farmers in southern Kyhushu, Japan. *J. Warm Reg. Soc. Anim. Jpn*., **54**:87–98.

Van Reeuwijk L. P. (1995): Procedures for Soil Analysis. Technical paper 9, 5th edition, ISRIC, Wageningen.

Van Soest P. J. (1994): Nutritional Ecology of the Ruminant, Comstock Publishing Associates. A division of Cornell University Press, Ithaca and London, 476p.

Van Soest P. J. and Robertson J.B. (1985): Analysis of Forages and Fibrous Foods. A Laboratory Manual for Animal Science 613. Cornel University, Ithaca, New York, USA, 202p.

Van Soest P.J. (1982): Nutritional ecology of the ruminant. O & B books, Corvallis, Oregon, USA, Pp425-457.Wassie W.A., Tsegay B.A., Wolde A.T. and Limeneh B.A. (2018): Evaluation of morphological characteristics, yield and nutritive value of Brachiaria grass ecotypes in northwestern Ethiopia. *Agric and Food Secur*, **7:**1-10.

Vandermeer J., van Noordwijk M., Anderson J., Ong C. and Perfecto I. (1998): Global change and multi-species agroecosystems: concepts and issues. *Agric Ecosyst Environ.*, **67**:1–22.

Walkley A. (1947) A Critical Examination of a Rapid Method for Determining Organic Carbon in Soils – Effect of Variations in Digestion Conditions and of Inorganic Soil Constituents. *Soil Science*, **63**(4): 251-264.

White P.J., George T.S., Gregory P.J., Bengough A.G., Hallett P.D. and McKenzie B.M. (2013): Matching roots to their environment. *Annals of Botany*, **112**: 207–222.

Whitehead D.C. (1995): Legumes Biological Nitrogen Fixation and interaction with grasses. Whitehead: DC (Ed) Grassland Nitrogen, CAB International. Wallingford. UK: Pp35-57.

Wijitphan S., Lorwilai P. and Arkaseang C. (2009): Effects of plant spacing on yields and nutritive values of elephant grass (*Pennisetum purpureum* Schum.) under intensive management of nitrogen fertilizer and irrigation. *Pakistan Journal of Nutrition*, **8**(8):1240-1243.

Woodard K.R., Prine G.M. and Bates D.B. (1991): Silage characteristics of elephant grass as affected by harvest frequency and genotype. *Agronomy Journal*, **93**: 347-551.

Worku B., Denbela H. and Tekleyohanis B. (2017): "Effect of Planting Space and Fertilizer Rate on Productivity of Desho Grass (*Pennisetum Pedicellatum*) in Jinka Agricultural Research Center, Southern Ethiopia ", *International Journal of Research in Agriculture and Forestry*, **4**(11):14-19.

Workye M., Aschalew A. and Kirkim D. (2018): "Improved forage production practice and challenges in Libokemkem District, Ethiopia". Agricultural Research Communication Centre. *Agric. Sci. Digest.*, **38**(4): 280-284.

Yasin M., Asghar Malik M. and Shafi Nazir M. (2003): Effect of different spatial arrangement on forage yield, yield components and quality of Mott Elephant grass. *Pakistan Journal of Agronomy*, **2**: 52-58.

Yayneshet, T. (2010): Feed Resources Available in Tigray Region, North Ethiopia, For Production of Export Quality Meat and Livestock, Addis Ababa, Ethiopia.

Yildirim E. and Turan M. (2013): Growth, Yield and Mineral Content of Broccoli Intercropped with Lettuce. *The Journal of Animal and Plant Sciences*, **23**(3): 919-922.

Yossif A.M. and Ibrahim Y.M. (2013): Effect of fertilizer (Urea, Farmyard and Chicken Manure) on growth and yield of Rhodes grass (*Chloris gayana* L. Kunuth). *Universal Journal of Plant Science*, **1**(3):85-90.

Zahid M.S., Haqqani A.M., Mufti M.U. and Shafeeq S. (2002): Optimization of N and P Fertilizer for Higher Fodder Yield and Quality in Mott elephant grass under irrigation-cum Rain fed Conditions of Pakistan. *Asian Journal of Plant Sciences*, **1**(6): 690-693.

Zailan M. Z., Yaakub H. and Jusoh S. (2018): Yield and nutritive quality of elephant grass (*Pennisetum purpureum*) cultivars as fresh and ensiled fodder. *The Journal of Animal & Plant Sciences*, **28**(1): 63-72.

Zand N. and Shakiba M. R. (2013): Effect of plant density and nitrogen fertilizer on some attribute of grain sorghum (*sorghum bicolor* (l.) moench*). International journal of Advanced Biological and Biomedical Research*, **1**(12): 1577-1582.

Zewdie W., Yoseph M. and Bram W. (2011): Peri-urban dairy production system in relation with feed availability in the highlands of Ethiopia. *World Appl. Sci. J*., **13**(7): 1712-1719.

Zewdenesh D., Bizuayehu T. and Daniel B. (2011): Leaf, essential oil and Artemisinin yield of Artemisia (*Artemisia annua* L.) as influenced by harvesting age and plant population density. *World. J. Agr. Sci*., **7**(4): 404-412.

Zhang F. and Li L. (2003): Using competitive and facilitative interactions in intercropping systems enhances crop productivity and nutrient-use efficiency. *Plant and Soil*, **248**: 305-312.

Zhang X., Gu H., Ding C., Zhong X., Zhang J. and Xu N. (2010): Path coefficient and cluster analyses of yield and morphological traits in elephant grass (*Pennisetum purpureum)*. *Tropical Grasslands,* **44**:95–102.

Zinash S., Seyoum B., Lulseged G. and Tadesse T.T. (1995): Effect of harvesting stage on yield and quality of natural pasture in the central high lands of Ethiopia. In: Proceedings of 3rd national conference of the Ethiopian society of animal production. 27-29, April 1995, Addis Ababa, Ethiopia, Pp16-322.

8. APPENDICES

Appendix A1. Holetta Agricultural Research Center (Some Photos)

Plot/Land preparation

Root spliting and planting of elephant grass


Vetch seed sowing



Sample collection

Frost cccurrence at the beginning of dry season


Hoeing of nitrogen fertilizer application and plant spacing treatment plots


Harvesting height and nitrogen fertilizer treatment


Data collection

Sample drying and grinding

Appendix A2. Debre Zeit Agricultural Research Center (Some Photos)

Plot/Land preparation

Elephant grass Root split transportation from Holetta to Debre Zeit Recsearch Center


Vetch intercropped with elephant grass treatment after hoeing


Vetch intercropping treatment and height measuring at harvest

Hoeing of elephant grass harvesting height and nitrogen fertilizer treatment

Nitrogen fertilizer and plant spacing treatment sample collection

Appendix B1. Combined Analysis of variance for forage dry matter yield (TDMY, t ha^{-1}) of elephant grass + vetch species during year 1 and year 2 as affected by vetch intercropping and plant spacing over locations and years

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	940.188906	940.188906	110.12	<.0001
year	1	1455.486084	1455.486084	170.48	<.0001
intcr	2	219.643668	109.821834	12.86	<.0001
spac	3	156.503941	52.167980	6.11	0.0008
intcr*spac	6	70.570249	11.761708	1.38	0.2317

R-Square	Coeff Var	Root MSE	TDMY Mean
0.805891	26.06237	2.921936	11.21132

Appendix B2. Combined Analysis of variance for forage crude protein (CP) content of elephant grass during year 1 and year 2 as affected by vetch intercropping and plant spacing over locations and years

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	237.930625	237.930625	30.95	<.0001
year	1	2874.746944	2874.746944	373.97	<.0001
intcr	2	1203.566435	601.783217	78.28	<.0001
spac	3	12.936725	4.312242	0.56	0.6417
intcr*spac	6	7.921704	1.320284	0.17	0.9840

R-Square	Coeff Var	Root MSE	CP Mean
0.815461	23.19028	2.772559	11.95569

Appendix B3. Combined Analysis of variance for forage *in vitro* dry matter digestibility (IVDMD) of elephant grass during year 1 and year 2 as affected by vetch intercropping and plant spacing over locations and years

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	123.395069	123.395069	12.94	0.0005
year	1	6502.003225	6502.003225	681.91	<.0001
intcr	2	640.236051	320.118026	33.57	<.0001
spac	3	32.834247	10.944749	1.15	0.3325
intcr*spac	6	23.288465	3.881411	0.41	0.8733

R-Square	Coeff Var	Root MSE	IVDMD Mean
0.857448	5.061750	3.087871	61.00403

Appendix B4. Combined Analysis of variance for rapidly degradable fraction of vetch intercropping over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	15.3585446	15.3585446	53.19	<.0001
inter	2	107.1099168	53.5549584	185.46	<.0001
loc*inter	2	82.9128592	41.4564296	143.56	<.0001

R-Square	Coeff Var	Root MSE	A Mean
0.986199	2.683830	0.537371	20.02256

Appendix B5. Combined Analysis of variance for slowly degradable fraction of vetch intercropping over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	105.8992704	105.8992704	82.81	<.0001
inter	2	95.9883385	47.9941692	37.53	<.0001
loc*inter	2	44.6057043	22.3028522	17.44	0.0005

R-Square	Coeff Var	Root MSE	B Mean
0.951328	2.321502	1.130881	48.71334

Appendix B6. Combined Analysis of variance for rate of degradation of b fraction of vetch intercropping over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	0.00006094	0.00006094	3.13	0.1075
inter	2	0.00094713	0.00047357	24.30	0.0001
loc*inter	2	0.00026691	0.00013346	6.85	0.0134

R-Square	Coeff Var	Root MSE	C Mean
0.874908	8.091947	0.004415	0.054559

Appendix B7. Combined Analysis of variance for potential degradability (PD) of vetch intercropping over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	40.59936087	40.59936087	30.02	0.0003
inter	2	10.92488832	5.46244416	4.04	0.0518
loc*inter	2	6.67837806	3.33918903	2.47	0.1345

R-Square	Coeff Var	Root MSE	PD Mean
0.816608	1.691945	1.162974	68.73589

Appendix B8. Combined Analysis of variance for effective degradability (ED) of Vetch intercropping over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	19.2731500	19.2731500	30.11	0.0003
inter	2	122.8905760	61.4452880	95.99	<.0001
loc*inter	2	8.1082481	4.0541241	6.33	0.0167

R-Square	Coeff Var	Root MSE	ED Mean
0.959645	1.561111	0.800093	51.25147

Appendix C1. Combined Analysis of variance for forage dry matter yield (DMY, t ha^{-1}) of elephant grass as affected by harvesting height and nitrogen fertilizer over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	750.9750125	750.9750125	187.66	<.0001
height	2	218.7819090	109.3909545	27.34	<.0001
fert	3	107.2903306	35.7634435	8.94	<.0001
height*fert	6	28.0241799	4.6706966	1.17	0.3367

R-Square	Coeff Var	Root MSE	DMY Mean
0.836393	23.16388	2.000458	8.636111

Appendix C2. Combined Analysis of variance for forage crude protein yield (CPY, t ha^{-1}) of elephant grass as affected by harvesting height and nitrogen fertilizer over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	4.55516806	4.55516806	158.32	<.0001
height	2	1.38293611	0.69146806	24.03	<.0001
fert	3	1.04921528	0.34973843	12.16	<.0001
height*fert	6	0.23046389	0.03841065	1.34	0.2568

R-Square	Coeff Var	Root MSE	CPY Mean
0.823247	22.62038	0.169621	0.749861

Appendix C3. Combined Analysis of variance for forage crude protein (CP) of elephant grass as affected by harvesting height and nitrogen fertilizer over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	10.74933889	10.74933889	48.63	<.0001
height	2	4.02560833	2.01280417	9.11	0.0004
fert	3	4.86137778	1.62045926	7.33	0.0003
height*fert	6	1.69588056	0.28264676	1.28	0.2817

R-Square	Coeff Var	Root MSE	CP Mean
0.632981	5.306675	0.470171	8.860000

Appendix C4. Combined Analysis of variance for forage *in vitro* dry matter digestibility (IVDMD) of elephant grass as affected by harvesting height and nitrogen fertilizer over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	120.6163347	120.6163347	163.19	<.0001
height	2	48.3662111	24.1831056	32.72	<.0001
fert	3	8.7349153	2.9116384	3.94	0.0127
height*fert	6	3.1449222	0.5241537	0.71	0.6435

R-Square	Coeff Var	Root MSE	IVDMD Mean
0.811397	1.268576	0.859716	67.77014

Appendix C5. Combined Analysis of variance for rapidly degradable fraction of elephant grass as affected by harvesting height over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	0.56081110	0.56081110	2.95	0.1166
height	2	48.52161959	24.26080979	127.61	<.0001
loc*height	2	13.41508809	6.70754404	35.28	<.0001

R-Square	Coeff Var	Root MSE	A Mean
0.970793	2.447603	0.436030	17.81459

Appendix C6. Combined Analysis of variance for slowly degradable fraction of elephant grass as affected by harvesting height over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	3.56774376	3.56774376	1.49	0.2501
height	2	2.78622958	1.39311479	0.58	0.5766
loc*height	2	19.12445118	9.56222559	4.00	0.0530

R-Square	Coeff Var	Root MSE	B Mean
0.602857	2.790367	1.546964	55.43944

Appendix C7. Combined Analysis of variance for rate of degradation of b fraction of elephant grass as affected by harvesting height over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	0.00032679	0.00032679	83.32	<.0001
height	2	0.00005028	0.00002514	6.41	0.0162
loc*height	2	0.00002188	0.00001094	2.79	0.1090

R-Square	Coeff Var	Root MSE	C Mean
0.911139	5.716703	0.001980	0.034644

Appendix C8. Combined Analysis of variance for potential degradability (PD) of elephant grass as affected by harvesting height over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	1.29948694	1.29948694	0.58	0.4621
height	2	74.55882745	37.27941373	16.77	0.0006
loc*height	2	1.63940514	0.81970257	0.37	0.7006

R-Square	Coeff Var	Root MSE	PD Mean
0.790086	2.035117	1.490806	73.25403

Appendix C9. Combined Analysis of variance for effective degradability (ED) of elephant grass as affected by harvesting height over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	48.2040894	48.2040894	276.55	<.0001
height	2	109.1845600	54.5922800	313.20	<.0001
loc*height	2	4.0713383	2.0356691	11.68	0.0024

R-Square	Coeff Var	Root MSE	ED Mean
0.989483	0.881572	0.417500	47.35856

Appendix D1. Combined Analysis of variance for forage dry matter yield (DMY, t ha^{-1}) of elephant grass as affected by nitrogen fertilizer and plant spacing over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	1124.565051	1124.565051	287.27	<.0001
spac	3	149.768471	49.922824	12.75	<.0001
fert	3	236.317173	78.772391	20.12	<.0001
spac*fert	9	19.027102	2.114122	0.54	0.8409

R-Square	Coeff Var	Root MSE	DMY Mean
0.835792	22.46580	1.978535	8.806875

Appendix D2. Combined Analysis of variance for forage crude protein yield (CPY, t ha^{-1}) of elephant grass as affected by nitrogen fertilizer and plant spacing over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	5.98001667	5.98001667	209.59	<.0001
spac	3	0.71179167	0.23726389	8.32	<.0001
fert	3	2.21992500	0.73997500	25.93	<.0001
spac*fert	9	0.13518333	0.01502037	0.53	0.8511

R-Square	Coeff Var	Root MSE	CPY Mean
0.805912	23.90309	0.168915	0.706667

Appendix D3. Combined Analysis of variance for forage crude protein (CP) content of elephant grass as affected by nitrogen fertilizer and plant spacing over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	7.49283750	7.49283750	41.40	<.0001
fert	3	18.34695000	6.11565000	33.79	<.0001
spac	3	0.49659167	0.16553056	0.91	0.4379
fert*spac	9	0.93954167	0.10439352	0.58	0.8121

R-Square	Coeff Var	Root MSE	CP Mean
0.669474	5.212503	0.425405	8.161250

Appendix D4. Combined Analysis of variance for forage *in vitro* dry matter digestibility (IVDMD) of elephant grass as affected by harvesting height and nitrogen fertilizer over locations

Source	DF	Type III SS	Mean Square	F Value	Pr > F
loc	1	204.7796260	204.7796260	1169.35	<.0001
fert	3	16.4203865	5.4734622	31.26	<.0001
spac	3	0.2806865	0.0935622	0.53	0.6602
fert*spac	9	1.6424177	0.1824909	1.04	0.4151

R-Square	Coeff Var	Root MSE	IVDMD Mean
0.943040	0.639893	0.418476	65.39781

Appendix E. List of Publications from PhD Dissertation

1. Bizelew G., Berhan T., Getnet A. and Fekede F. (2020). Effects of Spacing of Elephant Grass and Vetch Intercropping on Agronomic Performance and Herbage Yield of Elephant Grass. *Ethiopian Journal of Agricultural Science*, 30(2):13-30.

   https://www.researchgate.net/publication/341277445_Effects_of_Spacing_of_Elephant_Grass_and_Vetch_Intercropping_on_Agronomic_Performance_and_Herbage_Yield_of_Elephant_Grass

   https://www.ajol.info/index.php/ejas/article/view/195125

   https://www.ajol.info/index.php/ejas/article/view/195125/184305

2. Bizelew G., Berhan T., Getnet A. and Fekede F. (2019). Effect of Harvesting Height and Nitrogen Fertilization on Herbage Yield and Nutritional Qualities of Elephant Grass in the Central Highlands of Ethiopia. *Global Veterinaria*, 21(5): 287-297.

   https://www.idosi.org/gv/gv21(5)19/7.pdf

   https://www.researchgate.net/publication/341277347_Effect_of_Harvesting_Height_and_Nitrogen_Fertilization_on_Herbage_Yield_and_Nutritional_Qualities_of_Elephant_Grass_in_the_Central_Highlands_of_Ethiopia