EFFECTS OF INTEGRATED VERMICOMPOST AND NPSB FERTILIZERS, AND CUTTING INTERVALS ON DRY MATTER YIELD AND NUTRITIONAL VALUE OF ALFALFA (*Medicago sativa*) IN SOUTH SODO WOREDA, EAST GURAGE ZONE, CENTERAL ETHIOPIA

MSc. THESIS

HAILU SEIFU

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Effects Of Integrated Vermicompost And Npsb Fertilizers, And Cutting Intervals On Dry Matter Yield And Nutritional Value Of Alfalfa (*Medicago Sativa*) In South Sodo Woreda, East Gurage Zone, Centeral Ethiopia

HAILU SEIFU

MAJOR ADVISOR: TESFAYE FEYISA (PhD)

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APPROVAL SHEET

WOLKITE UNIVERSITY

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We, hereby certify that we have read and evaluated this Thesis titled "**Effects of Integrated NPBS and Vermicompost, and Cutting Intervals on Dry Matter Yield and Nutritional Value of Alfalfa (*Medicago Sativa*) in South Sodo Woreda, East Gurage Zone, Central Ethiopia**" prepared under our guidance by Hailu Seifu. We recommend that the thesis shall be submitted as fulfilling the requirements for the award of a MSc. degree in Animal Production.

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Name of Major Advisor Signature Date

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Name of CO- Advisor Signature Date

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As the members of the Board of Examiners of the Master Thesis open defense examination, we have read and evaluated this thesis prepared by Hailu seifu and examined the candidate. We hereby certify that, the thesis is accepted for fulfilling the requirements for the award of the Degree of Master of science (MSc.) in Animal Production.

1. ______________________ __________________ _________________

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Final approval and acceptance of the Thesis is contingent up on the submission of its final copy to the Council of Postgraduate Program (CPGS) through the candidate's department or school graduate committee (DGC or SGC).

DEDICATION

This thesis is dedicated to my lovely wife and family, who have provided encouragement, and showered me with love throughout my journey towards success in life.

STATEMENT OF THE AUTHOR

First, I declared that this thesis is a result of my genuine work and that I have duly acknowledged all sources of materials used for writing. I submitted this thesis to Wolkite University in partial fulfillment for the Degree of Master of Science in Animal Production and it is deposited in the library of the University to be made available to borrowers for reference. I solemnly declared that I have not so far submitted this thesis to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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Place: Wolkite University,

Date of Submission: May, 2025

BIOGRAPHICAL SKETCH

The author was born on April 13, 1987 G.C. from his father Mr. Seifu Senbatu and mother Mrs. Elefensh Berhanemeskel in East Gurage zone Sodo woreda. He attended his elementary education at Wacho Elementary School and completed his secondary education at Sodo Buee Senior Secondary School. After completing his secondary education, he enrolled at Dilla Agricultural, Technical, Vocational, and Education Training (ATVET) College in September, 2007 where he obtained his diploma in Animal Science. After graduation, he employed in east Guraghe zone, sodo woreda, Aymelel kebele as Animal Science extension agent (Agricultural Development Agent) in October 2007 and served for 4 years. Then in 2012, he joined Dilla University for first degree study in Animal and Ranges Science and completed in October, 2016.

Then up on his graduation, he joined again East Guraghe zone, Sodo Woreda Agricultural office as Bee keeping expert, served as Natural resource coordinator, Land Administration and land use planning coordinator and Head of the South Sodo Woreda Agricultural Office from October 2017 to September 2021. Finally, he joined Wolkite University, College of Agriculture and Natural Resource, Department of Animal Science in 2021 to pursue his MSc study in Animal production.

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ABBREVIATIONS AND ACRONYMS

AADMY	Average adjusted dry matter yield
ADF	Acid detergent fiber
ADL	Acid detergent lignin
ADMY	Average dry matter yield
AGDP	Agricultural gross domestic product
ANOVA	Analysis of variance
ATA	Agricultural Transformation Agency
CEC	Cation exchange capacity
CIMMYT	International Maize and Wheat Improvement Center
CP	Crude protein
CSA	Central statistical agency
DM	Dry matter
DMY	Dry matter yield
DWss	Dry weight sub-sample
ETB	Ethiopian birr
FBY	Fresh biomass yield
FWss	Fresh weight sub-sample
GB	Gross benefit
LFN	Number of leaf per plant
LSD	Least Significance Difference
LSR	Leaf to steam ratio
MRR	Marginal rate of return
NDF	Neutral detergent fiber
NI	Net income
NPSB	Nitrogen, phosphorus, sulfur and boron
OC	Organic carbon

OM	Organic matter
PB	Primary branches
PBA	Partial budget Analysis
PLH	Plant height
RCBD	Randomized Complete Block Design
SB	Secondary branches
SE	Standard Error
SSWAO	South Sodo Woreda Agriculture Office
SSWPDO	South Sodo Woreda Planning Development Office
TLN	Number of Tiller per plant
TVC	Total variable cost
VC	Vermicompost

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ABSTRACT

This study was conducted in South Sodo Woreda, East Gurage Zone, and Central Ethiopia, to evaluate the effects of integrated NPSB fertilizer and vermicompost, and cutting intervals on the growth, biomass yield, and nutritional value of alfalfa (Medicago sativa L.). Two factors factorial experiment was laid out in a randomized complete block design (RCBD) with 16 treatment combinations (T1: Control (0kg/ha NPSB fertilizer+0 ton/ha vermicompost (VC)); T2: 0 kg/ha NPSB+2.5 ton/ha VC; T3: 0 kg/ha NPSB+5 ton/ha VC; T4: 0 kg/ha NPSB+7.5 ton/ha VC; T5: 50 kg/ha NPSB+0 ton/ha VC; T6: 50 kg/ha NPSB+2.5 ton/ha VC ; T7: 50 kg/ha NPSB+5 ton/ha VC; T8: 50 kg/ha NPSB+7.5 ton/ha VC; T9: 100 kg/ha NPSB+0 ton/ha VC; T10: 100 kg/ha NPSB+2.5 ton/ha VC; T11: 100 kg/ha NPSB+5 ton/ha VC; T12: 100 kg/ha NPSB+7.5 ton/ha VC; T13: 150 kg/ha NPSB+0 ton/ha VC; T14:150 kg/ha NPSB+2.5 ton/ha VC; T15: 150 kg/ha NPSB+5 ton/ha VC; T16: 150 kg/ha NPSB+7.5 ton/ha VC) and three CUTTING INTERVALS s (1^{st} cut, 2^{nd} cut and 3^{rd} cut) with three replications. Soil samples were analyzed for physicochemical properties before sowing, and agronomic parameters such as plant height, tiller number, leaf count, leaf-to-stem ratio, and days flowering were recorded. Biomass yield was assessed at 50% flowering, while forage quality was determined by analyzing it for crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL). The results demonstrated that integrated fertilizer management significantly ($P<0.05$) enhanced both alfalfa yield and quality. The highest CP content (22.89%) and lowest fiber fractions (NDF: 30.35%, ADF: 14.51%) were recorded in the treatment received 100 kg NPSB/ha + 5 t/ha vermicompost (T11), while the control (T1) had the lowest CP (15.71%). The tallest plants (94.46 cm) were observed in T16 (150 kg NPSB + 7.5 t/ha vermicompost). Fresh and dry biomass yields were significantly ($P<0.05$) higher in T11 which achieved the highest dry matter yield (10,57t/ha representing 39.08% increase over the control. Cutting intervals also influenced yields, with the third cut producing 27% higher biomass than the first. Economic analysis showed T11 yielded the highest net benefit (350,600 ETB/ha) and marginal rate of return (4,510%). Additionally, higher fertilizer rates promoted early flowering in T11 in which 50% of flowering achieved at 60.21 days compared to 74 days in the control. These findings highlight the synergistic effects of organic and inorganic fertilizers in improving alfalfa productivity and nutritive value. Integrating 100 kg NPSB/ha with 5 t/ha vermicompost (T11) proved to be the most effective treatment, supporting its adoption as a sustainable fertilizer management strategy for enhanced forage production.

Keywords: *Alfalfa, biomass yield, chemical composition, NPSB fertilizer, vermicompost*

1. INTRODUCTION

1.1. Background

Agriculture plays a key role in global economic development, food security, and poverty alleviation, particularly in rural areas where livelihoods are closely tied to farming systems (Mozumdar & Lavlu, 2012). Within the agricultural sector, livestock husbandry is a fundamental component, contributing significantly to income generation, food supply, and sustainable land management (Randolph *et al*., 2007). Beyond their economic and nutritional benefits, livestock improve soil fertility through manure application, which enhances crop productivity and promotes ecological sustainability (Sere *et al*., 2008). Consequently, livestock production serves as a key driver of economic growth, food security, and poverty reduction, particularly across Africa (Lokuruka, 2020).

Ethiopia, has the largest livestock population in Africa; 70.29 million cattle, 40 million sheep, 51 million goats, 9.9 million donkeys, 2.1 million horses, 0.35 million mules, 8 million camels, 49 million chickens, and 6.9 million beehives (CSA, 2021) which relies heavily on the livestock sector for economic and agricultural sustainability. However, livestock productivity remains constrained by a shortage of quality feed resources, both in terms of quantity and nutritional value (Andualem et al., 2016). The primary feed sources for Ethiopian livestock include natural pastures (54.59%), crop residues (31.60%), hay (6.85%), agro-industrial byproducts (1.53%), improved feed (0.31%), and other supplementary sources such as vegetable and fruit waste (5.11 CSA, 2020). Unfortunately, conventional feeds such as natural pasture, crop residues, hay and household left over are often deficient in essential nutrients, particularly protein and energy, thereby limiting the productive potential of livestock (Mekuyie *et al*., 2021).

To reduce these nutritional deficiencies and improve livestock productivity, the use of high-quality, high-yielding, and drought-tolerant forage species is highly recommended (Balehegn, 2020). Leguminous forage crops, particularly alfalfa (*Medicago sativa*), is recognized for its superior protein content and ability to enhance ruminant nutritional value (Voisin *et al*., 2014).

Alfalfa, widely known as the "queen of forages," is one of the most significant perennial forage legumes globally due to its exceptional biomass yield, high protein content and adaptability to diverse agro ecological conditions (Gezahagn *et al*., 2017). Its deep root system, which can extend up to 4 meters in well-drained soils, allows it to withstand prolonged drought conditions by accessing deep water reserves (Hidosa, 2021). Additionally, alfalfa plays a critical role in soil health improvement through symbiotic nitrogen fixation, thereby reducing the need for artificial nitrogen fertilizers and enhancing soil fertility (Ma *et al*., 2021).

Alfalfa supplementation has been demonstrated to significantly enhance livestock productivity, particularly in dairy cattle. Research indicates that cows supplemented with alfalfa exhibit increased milk yields (Tolera *et al*., 2012) and diets with a 30:70 alfalfa-to-roughage ratio result in improved nutrient intake and digestibility compared to conventional forage diets (Monteros *et al*., 2009). Moreover, the high carotenoid content of alfalfa contributes to improved coloration of egg yolks and body lipids in poultry production, further increasing its value as a high-quality feed component.

The successful cultivation of alfalfa requires appropriate agronomic management, particularly regarding soil fertility enhancement through fertilization. In tropical agricultural systems, soil nutrient depletion is a critical challenge that necessitates the use of either organic or inorganic fertilizers to maintain sustainable production (Akande *et al*., 2007). The application of inorganic fertilizers, particularly nitrogen (N), phosphorus (P), sulfur (S), and boron (B) (NPSB fertilizers), has been widely promoted to address declining soil fertility, short fallow periods, and land-use intensification (Amuioyegbe *et al*., 2007). Studies have demonstrated that phosphorus application, in particular, significantly improves alfalfa growth, forage yield, and nutrient content (Berg *et al*., 2007).

In contrast, organic fertilizers such as vermicompost provide a sustainable alternative or supplement to inorganic fertilizers. Vermicompost is produced through the microbial degradation of organic matter facilitated by earthworms, resulting in nutrient-rich compost that enhances soil structure, microbial activity, and nutrient availability for plant uptake (Lazcano *et al.*, 2013). Vermicompost is particularly valuable as it contains high levels of bioavailable nitrogen, including nitrate (NO_3^-) and ammonium (NH_4^+), which are readily absorbed by plants (Alemneh & Ygrem, 2017). Long-term applications of organic fertilizers have been shown to improve both leaf and stem nutritional quality in alfalfa, thereby enhancing its overall forage value (Hakl *et al.*, 2021).

While extensive global and regional research has explored the effects of inorganic and organic fertilizers on forage crop productivity, there remains limited empirical data on the combined influence of NPSB fertilizers and vermicompost on alfalfa yield and nutritive value in Ethiopia. Given the country's pressing need for high-quality livestock feed, location-specific studies are crucial for determining optimal fertilization strategies in Ethiopia's diverse agro ecological conditions.

1.2. Statement of the Problem

The shortage of feed is one of the main challenges and obstacles limiting the success and profitability of the animal production in Ethiopia. The feed resource base for livestock is shrinking, and the cost of protein to feed animals has become too expensive (Tolera, 2012). In commercial animal production, feed costs account for 60–70% of total costs (Sayda *et al*., 2011). Animal diets, including natural pastures, forage crops, forage trees, crop residues, and non-conventional forages, are used in various regions of Ethiopia (Sefa, 2017). However, feed shortages and low feed quality have become major constraints for livestock production in the country (Alemayehu *et al*., 2017). Shortage of feed is exacerbated mainly during the dry season (Zewdie, 2010). Droughts and dependence on rainfall are factors that affect forage production in Ethiopia,

The use of adaptable, high-yielding, and drought- tolerant improved forages like alfalfa is important to increase the productivity of the livestock due to their better nutritive value but the productivity is very low due to rapid decline of soil nutrients value and productivity (Akande *et al*., 2007) which enhances the need for inorganic fertilizers. According to Sun *et al* (2012), chemical fertilizers play an important role in meeting the nutritional needs of plants, thereby increasing production. However, in the current situation, the improper use of fertilizers cause of both economic and environmental issues that are frequently challenging to address, especially in developing nations (Sutton *et al.,* 2011; Sun *et al*., 2012). The main problems with non-selective, lower or excessive use of synthetic fertilizers are widespread problems of soil nutrient depletion, perturbation of soil response, development of plant nutrient imbalances, depletion of soil organic matter, reduction of the abundance of beneficial soil micro-organisms and increase in environmental pollution (Mengistu *et al*., 2017).

In addition to environmental concerns, the growing cost of chemical fertilizers combined with smallholder farmers' a growing interest among the scientific and farming communities to shift their focus from chemical-only agriculture to integrated nutrient management strategies that make use of both organic and inorganic nutrient forms (Singh et al., 2010). Because the soil-plant system's nutrient turnover is so high in intensive farming, neither chemical fertilizers nor organic or biological sources by themselves can provide production sustainability (Javaria and Khan, 2011).

The lack of mineral nutrients, the sole application of organic sources, declines to maintain and synchronize the necessary nutrient supply of growing plants because mineralization takes time to release nutrients that are uptake by the plant (Akhtar *et al*., 2011). Recent years have seen a significant increase in the integrated use of organic and inorganic nutrient sources (Prativa and Bhattarai, 2011). Organic sources enhance the physical and biological health of the soil in addition to providing nutrients, which increases the availability of both applied and native nutrients. Combining chemical fertilizers with organic material is more effective, economical, and sustainable for agriculture and the environment (Reddy, 2011; Koushal *et al*., 2011). Given the central role of alfalfa in the local economy and food systems, it is essential to conduct systematic research to evaluate the effects of various fertilizer types and application rates on alfalfa’s dry matter yield and nutritional value. Such information would provide evidence-based recommendations for local farmers, helping them to enhance their production practices, improve livestock health, and ultimately increase their income.

1.3. Research Hypothesis

The following major hypothesis was tested

- The interaction effects of integrated vermicompost and NPSB fertilizers, and Cutting Intervals significantly impacts the dry matter yield and nutritional value of alfalfa.

1.4. Objectives of the Study

1.4.1. General Objective

- ✓ The overall objective of this study was to investigate the effects of integrated vermicompost and NPSB fertilizer application and cutting intervals on the dry matter yield and nutritional value of alfalfa.

1.4.2. Specific Objectives

The specific objectives of the study were:

- ✓ To evaluate the effects of integrated vermicompost and NPSB fertilizers and cutting intervals on the dry matter yield of alfalfa.
- ✓ To assess the effects of integrated vermicompost and NPSB fertilizers on the chemical composition of alfalfa.
- ✓ To examine the interaction effects of vermicompost, NPSB fertilizers, and cutting intervals on the dry matter yield and nutritional value of alfalfa.
- ✓ To evaluate the economic feasibility of using integrated vermicompost and NPSB fertilizers along with optimized cutting intervals for alfalfa forage production.

1.4. Significant of the Study

This study is primarily concerned with the effects of integrated vermicompost and NPSB fertilizers, and cutting intervals on alfalfa dry matter yield and nutritional value. Alfalfa has the peculiar advantages of easy adaptability to stress conditions, efficient production of feed protein, and year-round availability (Hidosa and Dechassa, 2021). And NPSB fertilizer and vermicompost, which are reasonably available, have a high potential to solve the existing feed shortage and reduce feed costs by increasing the productivity of alfalfa (Alemneh and Yigrem, 2018; Tadesse *et al*., 2020).

The use of alfalfa was improving the livestock industry since it is a good source of protein. The most popular and highest-yielding perennial forage crop farmed worldwide is alfalfa, a forage legume. Compared to other forage legumes, it provides more protein per unit of area (Capstaff *et al*., 2018). Alfalfa symbiotically fixes greater amounts of atmospheric nitrogen than most other legume species, and it's possible to introduce larger quantities of fixed nitrogen into agricultural cropping systems as a replacement for fertilizer nitrogen. It can also grow in a variety of soil types and climate zones, producing large yields of nutrient-rich, palatable feed. It is critical to reduce the cost of competing with expensive human food (Geleti *et al*., 2014).

Economically, this research offers valuable insights for smallholder farmers and commercial forage producers. The cost-benefit analysis of different fertilizer combinations and cutting regimes provides practical guidance for optimizing input use efficiency and maximizing returns on investment (Balehegn *et al*., 2020)

The yield and quality data generated in this study enable accurate estimation of production costs per unit of digestible nutrients, which is crucial for informed decision-making in forage-based livestock enterprises. These economic analyses are supported by robust experimental data collected over multiple growing seasons, enhancing their reliability and applicability (Mekuriaw *et al*., 2021).

At the policy level, this thesis contributes to evidence-based agricultural planning. The documented effects of integrated nutrient management on alfalfa performance provide scientific justification for promoting organic-mineral fertilizer combinations in national extension programs. The cutting interval recommendations offer technical guidelines for forage management in extension packages. These policy-relevant findings align with Ethiopia's agricultural transformation agenda and climate-resilient green economy strategy (Tadesse *et al.*, 2020; Assefa *et al*., 2022).

2. LITERATURE REVIEW

2.1. Feed Rresources in Ethiopia

Ethiopia has a variety of resources for animal feed, most of which are dependent on seasonal availability. Feed supplies vary depending on the type of agricultural operations such as the mode and intensity of crop production, population density, agro-ecology, the time of year, and environmental factors such as rainfall patterns (Seyoum *et al*., 2003). Natural pasture, crop residues, improved forage, hay, and agro-industrial byproducts are the major livestock feed resources in Ethiopia (Mengistu *et al*., 2017).

Table 1: The proportion of Animal Feed Resources in Ethiopia

Number	Feed type	Percentage
1	Natural pasture	54.59%
2	Crop residues	31.60%
3	Hay	6.85%
4	Agro-industrial by-products	1.53%
5	Improved forage	0.31%
6	Vegetable and fruit waste	5.11%

Source: CSA (2020)

2.1.1. Natural Pasture

Natural pasture is a critical supply of ruminant cattle feed in developing countries (Balehegn *et al*., 2020). Mekasha *et al*. (2015) mentioned that approximately 55.96 % of the overall feed sources are derived from grazing land. However, natural pastures are categorized as poor quality roughage with a low intake (Berhanu *et al*., 2009) and poor digestibility due to its low crude protein and metabolizable energy (Mekuriaw, 2018). Natural pasture is the main feed source for livestock in Ethiopia. However, its quality and availability have declined due to crop farming expansion, overgrazing, and land degradation (Mengistu *et al*., 2017). The low nutritional value of pastures is likely caused by poor plant diversity (especially the lack of grass-legume mixtures) and improper land management. Factors such as lack of fertilizer use, uncontrolled grazing, climate change, and inconsistent soil improvement practices have worsened the problem (Ibrahim, 2021).

2.1.2. Crop Residues

Crop residues supply approximately 50% of the total ruminant feed in the mixed crop-livestock farming systems of the Ethiopian highlands, where cereal production dominates. During the dry season, their contribution can increase to as much as 80% of the total feed resources (Duncan *et al*., 2016; Assefa *et al*., 2023). With the ongoing conversion of grazing lands into croplands to meet the rising demand for grain, the dependence on crop residues as livestock feed is expected to further intensify (Mekonnen *et al*., 2024; Terefe *et al*., 2023).

Crop residues exhibit significant variability in chemical composition and digestibility, influenced by varietal differences and agronomic practices (Redin *et al*., 2014). The feeding value of these residues is often limited due to their low voluntary intake and poor digestibility. Recent studies indicate that the crude protein (CP) content of crop residues ranges between 2.4% and 7%, while their in-vitro dry matter digestibility (IVDMD) varies from 34% to 52% (Faji et al., 2022; Mekonnen et al., 2023). Comparative analyses showed that cereal straws typically contain 4.5% CP, 79.4% neutral detergent fiber (NDF), and 51.1% IVDMD, whereas pulse straws have higher nutritional values (7% CP, 62.9% NDF, and 63.5% IVDMD) (Tesfaye & Animut, 2023). Additionally, oil plant straws exhibit intermediate values, with 5.4% CP and 66.4% NDF (Getahun *et al*., 2024).

2.1.3. Agro-industrial By-Products

The grains and oilseeds processing by-products play a big role in addressing the problem of insufficient feed supplies and qualities. Agro-industrial byproducts are highly valued as livestock feeds due to their high protein or energy content, or both. These byproducts improve ruminant feeding efficiency because of their high digestibility and low fiber content. For example, oilseed cakes contain more than 35% crude protein (CP) and 50–70% in-vitro organic matter digestibility (IVOMD), while flour milling byproducts (such as wheat bran) typically provide 12–18% CP and over 80% IVOMD (Assefa & Kechero, 2018; Dereje &

Diriba, 2021). Brewer's grains offer 20–25% CP and serve as a cost-effective protein supplement (Tesfaye *et al*., 2020). Due to their high nutrient density, incorporating agro-industrial byproducts into low-quality basal feeds enhances animal performance and mitigates dietary nutrient deficiencies (Mekonnen *et al*., 2022)

2.1.4. Improved Forages

Beginning in the 1970s, improved multipurpose forage crops and trees such as Sesbania species Leucaena leucocephala, Calliandra species and Chamaecytisus palmensis were introduced, made popular, and used in Ethiopia's mixed crop-livestock system to supplement the abundant roughage feed supplies (Agza, 2013). It has been reported that initiatives to create improved forages have had unsatisfactory and restricted success rates, with contributions of less than 1% (Muir *et al*., 2011). Still under the current Ethiopian conditions, cultivated fodder crops like oats, vetch, alfalfa, and fodder beet are not well grown (Mengistu, 2012).

Poor adoption of enhanced forage production and lack of land in the mixed crop-livestock production system are the main reasons which downgrade its uses. In order to maintain per capita agricultural yield in Ethiopia's highlands, the immediate response to population pressure is focused on an increase in the cultivated area. Hence, competition for land resources between livestock and agriculture activities may increase (Mekuria *et al*., 2018).

2.2. Botanical description of alfalfa

Alfalfa (*Medicago sativa*), also called lucerne, is a perennial crop, which means it was grown for several years after planting. Alfalfa is a flowering plant in the legume family Fabaceae (El-Ramady *et al.,* 2020). It is grown as a significant forage crop in numerous nations all over the world. It serves as a cover crop, hay, silage, and for grazing. North America refers to this plant as "alfalfa." The word "alfalfa," which means "excellent horse feed" and "horse power," is Arabic in origin (Roy *et al*., 2016).

In the United Kingdom, South Africa, and Australia, the name Lucerne is more frequently used (Roberts *et al*., 2009). It has tiny purple flowers that are followed by spiral fruits with two to three turns and 10 to 20 seeds in each. Temperate climates are where alfalfa originated. Since at least the time of the ancient Greeks and Romans, it has been grown for use as livestock fodder (Bilello, 2016).

The deep roots of alfalfa can extend as far as 4 meters, but in well-drained soils, they can go as far as 7 meters. It has upright, 1 m-tall stems that are glabrous or hairy on top. The trifoliate leaves have 10 to 45 mm long and 3 to 10 mm wide. Oval or circular shape includes five to forty yellow, blue, or purple flowers. Curly fruits have 2 to 8 seed pods that change from green to brown (Lesins, 2012). Alfalfa is one of the most adaptable crops in the world that quite adaptable and frequently grown in a variety of conditions, from hot desert places to chilly highland areas. It depends on all facets of crop management, including establishment, fertilization, harvest planning, pest, weed, and disease control, irrigation, and thrives on fertile and well-drained soils with a neutral pH as a perennial crop (Fernandez *et al*., 2019).

2.3. Importance of Producing Alfalfa

Alfalfa (*Medicago sativa L.*) serves as one of the most valuable forage crops globally, primarily used as high-quality feed for cattle, horses, poultry, pigs, and fish, with emerging applications in human nutrition (Kahyani *et al*., 2022). The crop's aerial parts are processed industrially into pigment-rich protein concentrates for animal feed (Blair *et al*., 2016). Beyond its role as livestock feed, alfalfa provides exceptional agronomic benefits as a perennial crop that enhances soil health through nitrogen fixation (Yang *et al*., 2010), organic matter accumulation, and improved water retention (Fernandez *et al*., 2019). Its extensive root system and year-round ground cover protect against soil erosion while supporting pollinator populations, making it valuable for both agriculture and ecosystem conservation (Fernandez *et al*., 2019). Alfalfa is typically harvested as hay or silage, with modern processing techniques enabling its conversion into meal, pellets, or fresh forage through grazing or cut-and-carry systems (Radovic *et al*., 2009).

The crop's economic importance stems from its remarkable biomass production potential, yielding over 80 t/ha of green matter and approximately 20 t/ha of dry matter (Adovi *et al*., 2009). Alfalfa forage is nutritionally superior to most other fodder crops, containing 17-25%

crude protein with a balanced amino acid profile (Dini *et al*., 2005; Markovi *et al*., 2007a), along with essential vitamins (A, E, K, and B-complex) and micronutrients critical for animal development (Tomic *et al*., 2001; Markovi *et al*., 2009). Its nutritional value is particularly crucial for dairy cattle, where crude protein levels exceeding 15% support optimal lactation and growth (Getachew *et al*., 2022). However, forage quality significantly depends on harvest management early-cut alfalfa (pre-bloom) maintains higher protein content (19-25%) and lower fiber, while mature stands (full bloom) show reduced protein (12-18%) and increased lignin, decreasing digestibility (Perez, 2020). The leaf fraction contains 2-3 times more protein than stems, making leaf retention during harvest critical for quality preservation (Doohong, 2022; Markovi *et al*., 2008). Alfalfa's agricultural value is further enhanced by its rapid regrowth after cutting, perennial longevity, and environmental stress tolerance, which ensure consistent yields across multiple growing seasons (Yang *et al*., 2010).

2.4. Agronomic Practice of Alfalfa

Alfalfa requires well-drained soil for optimum production. The usage of erosion control plants may be necessary on sloping fields where erosion is an issue (Undersander, 2011). A pH of 6.5 to 7.0 must be kept in alfalfa soil to permit the uptake of nitrogen and phosphate (Sulc *et al*., 2017). The year prior to seeding should be used to start field preparation. A long-lasting, fruitful stand was more likely if weeds are controlled before seeding. Before sowing alfalfa, control weeds with an efficient management program using the right pesticide and tillage combination and diseases that can harm seedlings, diminish fodder output, and destroy existing plants that thrive in moist soils (Sims *et al*., 2018). The rate and depth of seeding of alfalfa is a crop with tiny seeds, so proper seeding depth is crucial. The soil should be applied over the seed in a way that keeps it moist during germination while still allowing the tiny sprout to emerge at the surface.

The optimal seeding depth for alfalfa varies based on soil type to ensure successful germination and establishment. For medium and heavy-textured soils, planting seeds at a depth of 0.64 to 1.27 cm is recommended. In sandy soils, a slightly deeper planting of 1.27 to 2.54 cm advised to promote proper seedling emergence (Dixon *et al*., 2005).Alfalfa's early growth, effective stand establishment, and increased yield and quality are all facilitated by proper fertilization. Alfalfa's capacity for the competition is also enhanced by adequate fertility. Fields require different amounts of fertilizer (Hancock *et al*., 2009). Diseases can shorten the life of a stand, kill seedlings, reduce stand density, and lower yields. Selecting cultivars with high levels of disease resistance is the greatest method for disease control (Ratnadass *et al.*, 2012). Regardless of maturity stage, cut the first cutting 60 days after germination. This gets clear of a lot of annual weeds and makes the second cutting bloom at 10% (Modi *et al*., 2007).

2.5. Application of Fertilizer on Alfalfa Performance

Mineral fertilizer applications on alfalfa have been carried out over several decades and have usually found positive responses in terms of forage yield and yield components as a result of improved supplies of P and/or K (Berg *et al.*, 2007; He *et al*., 2017). Even while alfalfa nodulation can be stable and active throughout the growing season, alfalfa plants can fix large amounts of nitrogen by symbiotic N2 fixation (Chmelková *et al*., 2015). During times when soil nitrogen is scarce, crop growth may be promoted by supplemental N fertilization (Hakl *et al*., 2021). After 47–59 years of various fertilization management techniques, fertilizing just by manure applications during the entire crop cycle considerably increased the total alfalfa fodder output (Michal, *et al*., 2022). In contrast to mineral fertilization, long-term manure application in alfalfa has shown some promise for enhancing the nutritional value of both leaves and stems, which could increase the quality of the plant as a whole (Hakl *et al*., 2021).

2.5.1. Effect of Nitrogen on Dry Matter Yield and Nutritional Value of Alfalfa

Alfalfa (Medicago sativa L.) is a high-value forage legume with exceptional nitrogen-fixing capabilities, contributing 40–80% of its nitrogen requirement through symbiotic Rhizobium associations (Song *et al*., 2021). Due to its deep root system and efficient biological nitrogen fixation (BNF), alfalfa typically requires minimal external nitrogen fertilization (Jarvis, 2005). However, supplemental nitrogen may influence dry matter yield and nutritional composition under certain conditions.

In pure alfalfa stands, excessive nitrogen fertilization can reduce BNF efficiency and may not significantly improve biomass yield (Berg *et al*., 2023). Conversely, in alfalfa-grass mixtures, grasses can utilize nitrogen released from alfalfa root exudates and nodule decay, enhancing overall forage productivity without additional N inputs (Elgharably *et al*., 2021).

Nitrogen availability directly affects alfalfa's nutritional quality, particularly crude protein (CP) content. Studies show that while BNF meets basic nitrogen needs, strategic nitrogen application (20–50 kg N/ha) in deficient soils can increase CP by 8–12% without suppressing nodulation (Li *et al*., 2022). However, excessive nitrogen may reduce water-soluble carbohydrates and alter fiber fractions (NDF, ADF) potentially impacting digestibility

2.5.2. Effect of Phosphorus on dry matter yield and nutritional value of alfalfa

Phosphorus (P) plays a fundamental role in alfalfa (*Medicago sativa* L.) growth and development, significantly influencing both dry matter yield and nutritional quality. As one of the most essential macronutrients, phosphorus participates in numerous physiological processes including photosynthesis, energy transfer through ATP synthesis, respiration, cell division, and nitrogen fixation through rhizobial nodule formation (Mengel *et al*., 2001). Adequate phosphorus nutrition is particularly crucial for alfalfa, as it directly affects stand establishment, productivity, and persistence (Macolino *et al*., 2013). The nutrient's importance is further highlighted by its role in biological nitrogen fixation, where it enhances the size and quantity of Rhizobium nodules, thereby improving the plant's nitrogen acquisition capacity (Schwember *et al*., 2019).

The impact of phosphorus on alfalfa yield is most pronounced during the first harvest of the growing season, though the timing of application significantly affects fertilizer efficiency (Duncan *et al*., 2018). This seasonal variation in response underscores the importance of proper P management. Many agricultural soils, while containing substantial total phosphorus reserves, often have limited plant-available phosphorus due to chemical fixation, particularly in alkaline or acidic soil conditions. This limited availability frequently creates a need for targeted phosphorus fertilization in alfalfa production systems.

Phosphorus deficiency in alfalfa manifests through distinct symptoms including stunted growth, reduced tillering, smaller and darker green leaves, delayed maturity, and increased susceptibility to various diseases (Honghua *et al.*, 2021). These symptoms differ notably from nitrogen deficiency characteristics, providing important diagnostic clues for nutrient management. The deficiency not only reduces biomass production but also adversely affects forage quality parameters.

From a nutritional perspective, optimal phosphorus nutrition enhances several key quality aspects of alfalfa forage. It improves crude protein content through enhanced nitrogen fixation and metabolic activity, boosts energy content via efficient ATP-driven processes and promotes better mineral balance by facilitating root uptake of other essential nutrients (Zhang *et al* 2025). These combined effects make phosphorus management a critical factor in producing high-quality alfalfa forage with optimal yield potential. The relationship between phosphorus availability and alfalfa performance demonstrates the nutrient's dual importance in both quantity and quality of forage production, emphasizing the need for careful phosphorus management in alfalfa cultivation systems (Zhang *et al* 2020).

2.5.3. Effect of Sulfur on Dry Matter Yield and Nutritional Value of Alfalfa

Sulfur plays a critical role in alfalfa production as a structural component of essential amino acids (methionine and cysteine), proteins, and enzymes (Scherer, 2001). Alfalfa's sulfur requirement exceeds that of most cereal crops, typically ranging from 5-8 kg S per ton of dry matter produced (Chaudhary *et al.*, 2022). Modern agricultural practices have increased sulfur deficiency risks through several factors: (1) use of high-analysis fertilizers containing minimal sulfur, (2) declining organic matter inputs, (3) increased crop removal by high-yielding cultivars, and (4) reduced atmospheric S deposition (Katoch, 2018).

Sulfur deficiency manifests through distinct symptoms including uniform chlorosis (particularly in younger leaves), reduced leaf size, thin stems, and stunted growth (Yuan *et al.*, 2021). These morphological changes correspond with physiological impairments - reduced protein synthesis leads to 15-30% lower crude protein content and disproportionate accumulation of non-protein nitrogen compounds. The quality impacts extend beyond protein to affect sulfur-containing secondary metabolites that influence forage palatability and animal health (Scherer, 2008).

From a production perspective, severe S deficiency (soil S < 10 mg/kg) can reduce alfalfa yields by 20-40%, with the most significant impacts occurring in the second and subsequent harvests. The yield response to sulfur application follows a distinct threshold pattern, with little benefit above sufficiency levels but dramatic improvements when correcting deficiency (Chaudhary *et al*., 2022).

2.5.4. Effect of Boron on Dry Matter Yield and Nutritional Value of Alfalfa

Boron plays a critical role in alfalfa production systems, with this high-value forage crop requiring substantially greater boron concentrations than most other field crops. As a key structural component of cell walls and membranes, boron contributes significantly to alfalfa's growth and development. The optimal boron concentration in alfalfa tissues ranges between 30-80 ppm, with deficiency symptoms appearing when levels drop below 20 ppm (Epstein and Bloom, 2005). This micronutrient participates in several vital physiological processes including protein synthesis, nitrogen metabolism, and carbohydrate translocation, making it indispensable for achieving both high yields and superior forage quality (Ozturk *et al*., 2010).

Boron deficiency occurs most frequently under specific soil and environmental conditions. Sandy soils with low organic matter content are particularly prone to boron deficiency due to leaching losses, while alkaline soils (pH >7.5) exhibit strong boron adsorption, reducing its availability to plants (Nejad *et al*., 2020). Drought conditions further exacerbate boron deficiency by limiting mass flow to plant roots. These deficiency conditions manifest through distinct visual symptoms that progress from initial leaf thickening and curling in young leaves to more severe manifestations including rosette formation, corky stems, and ultimately death of apical meristems in advanced cases (Sakamoto, 2012).

The impact of boron deficiency on alfalfa productivity can be substantial, with severe deficiency (<15 ppm) potentially reducing dry matter yields by 25-40% (Brdar *et al*., 2020). Beyond yield reductions, boron deficiency negatively affects forage quality parameters, leading to 12-18% lower crude protein content and increased lignin concentration. These quality changes not only reduce the nutritional value of the forage but may also decrease its palatability to livestock. The combined effects on yield and quality make boron management particularly important in high-intensity alfalfa production systems. Effective boron management requires careful consideration of application rates and timing. Soil testing revealing hot-water extractable boron levels below 0.5 ppm indicates a high probability of deficiency, while levels between 0.5-1.0 ppm may warrant monitoring (Sapkota *et al*., 2018).

2.5.5. Effect of vermicompost on dry matter yield and nutritional value of alfalfa

The term "vermicomposting" comes from the Latin "vermi," which means "worm." Earthworms are utilized in this biological process to turn organic waste into nutrient-rich soil, which works as a breakdown agent for organic waste, a catalyst for microbial activity, and an accelerator of soil mineralization. Vermicompost is a product of these processes, which turn garbage into humus-like materials (Ansari *et al*., 2010). It is an excellent sustainable alternative to use as fertilizer and an excellent technique to support sustainable agriculture in small-scale farms Vermicompost (VC) is a slow-releasing organic fertilizer that provides essential macro- and micronutrients necessary for plant growth. It is rich in nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) (Towedros *et al.*, 2014). Additionally, it contains beneficial microbial populations, enzymes, and plant growth hormones, which enhance soil fertility and improve plant nutrient uptake (Singh et al., 2016).

The production of vermicompost involves the decomposition of organic wastes such as manure, green leaves, and other nutrient-rich materials. Supplementary inputs, including, weed, paper waste, and sawdust, have been tested to optimize its nutrient content (Tejada & Gomez, 2015). Several studies indicate that the application of vermicompost significantly increases the dry matter yield of crops, including alfalfa. Vermicompost enhances soil structure, increases water-holding capacity, and improves aeration, all of which contribute to better root development and biomass production (Ansari et al., 2010).

According to Singh *et al*. (2016), vermicompost contains beneficial micro and macronutrients, plant growth hormones, enzymes, and vitamins that collectively enhance plant growth and productivity. Research demonstrates that vermicompost application improves plant uptake of essential nutrients including nitrogen (N), phosphorus (P), potassium (K), and magnesium (Mg) (Kumar *et al*., 2022). This enhanced nutrient availability stems from two key mechanisms: (1) vermicompost's rich microbial community that includes nitrogen-fixing bacteria and phosphate-solubilizing microorganisms, and (2) its unique slow-release nutrient properties that synchronize with plant demand patterns (Singh *et al*., 2021). Furthermore, vermicompost contains bioactive compounds like humic acids that stimulate root development and improve water use efficiency in alfalfa (Zhang *et al*., 2023). Vermicompost application has been shown to improve the nutritional quality of crops by increasing their protein content, mineral concentration, and vitamin levels. The presence of bioavailable nutrients in vermicompost facilitates better nutrient absorption by plants, resulting in an increased crude protein percentage in alfalfa forage and vermicompost enhances microbial activity in the soil, which leads to better decomposition of organic matter and increased nitrogen nitrogen-fixing (Wang *et al.,* 2023).

Table 2: Nutrient content of vermicomposts

No	**Parameters**	**Vermicopost**
1	Ph	7.76—8.84
2	Organic carbon g/kg	2.84—2.8817
3	Total nitrogen g/kg	22.1—24.1
4	Available phosphorus g/kg	9.75—9.95
5	Organic matter g/kg	492.8—498.2
6	Total Sulphur g/kg	3.21—3.23
7	C/N ratio	12.17—12.43g
8	Potassium g/kg	15.01—15.39
9	Calcium g/kg	20.89—26.71
10	Znic g/kg	16.73—17.07
11	Iron g/kg	8.54—8.82
12	Cupper g/kg	0.93—1.01
13	Magnesium g/kg	6.64—6.84

Sources: Sutar (2009)

2.5.5.1. Agronomic Value of Vermicompost Use in Agriculture

Increased rate of germination: According to Arancon (2012), vermicompost encourages early germination due to the increased supply of nutrients and improvement of the environment's physical conditions. It was found, the seedlings germination rate increased considerably, even at 0-12% concentration of vermicompost extracts on tomato and lettuce. Similarly, Ievinsh (2011) reported that the germination percentage of 0 and 3% plants, showed increased germination of 7 and 13% when vermicompost extract was applied. According to (Ievinsh, 2011), there is improvement of soil conditions and increased availability of mineral nutrients after vermicompost application. The early emergence of seedlings is beneficial as it may encourage suppression of weeds and strong initial growth.

Increased canopy cover: Vermicompost may increase the leaf area and canopy size of leaves which consequently increases photosynthetic potential and yield. Vermicompost contains a high amount of nitrate which may move to the growth areas of the plant and increase the leaf area index (Abernethy, 2017). This in turn can increase the absorption of light, enabling the plant to undergo photosynthesis. This leads to a dry matter yield increase in plants. Papathanasiou *et al*. (2012) compared applications of fertilizers and compost on the yield of lettuce and found the highest leaf number (23.67) in the 10% vermicompost treatment and highest leaf dry weight (7.8 g) in the 20% vermicompost treatment.

Shoot and root elongation: Due to an improved supply of nutrients, crops fed with vermicompost may exhibit robust early development. Nitrate and potassium are highly available in vermicompost, facilitating quick nutrient absorption and plant elongation. Vermicompost may promote seedlings' vigorous early growth through improved root formation, stem elongation, and biomass output (Chavda & Rajawat, 2015). Similar findings were made by (Bajracharya *et al*., 2007), who discovered that adding vermicompost to fertilizer boosted the soybean shoot's dry weight. According to Suthar's. (2009) research, the yield of garlic plants rose following the application of vermicompost in comparison to the application of fertilizers. In comparison to the application of mineral fertilizer, leaf length was 0.6% longer, shoot dry weight was 31.4% heavier, and root length was 74.6% longer.

2.5.6. Dry matter yield of alfalfa

Alfalfa (*Medicago sativa* L.) is a high-yielding perennial forage legume whose productivity depends heavily on balanced nutrient management. Recent studies emphasize the importance of phosphorus (P), nitrogen (N), sulfur (S), boron (B), and organic amendments like vermicompost in maximizing dry matter yield (DMY) while maintaining forage quality (Putnam, 2022). Optimal fertilization strategies enhance root development, photosynthetic efficiency, and nutrient use efficiency, leading to sustainable alfalfa production systems.

Phosphorus is vital for energy transfer (ATP), root growth, and nitrogen fixation in alfalfa. Research confirms that P application significantly boosts DMY: 40 kg P ha^{-1} moderate yield increase (6-8 tons ha^{-1})80 kg P ha^{-1} Substantial improvement (9-11 tons ha^{-1})120 kg P ha^{-1} Peak DMY (12-14 tons ha^{-1}) (Zhang *et al.*, 2023).

Recent field trials show that P deficiency reduces regrowth capacity after cutting, while optimal P application enhances root biomass and drought tolerance (Wang et al., 2023). Excessive P (>150 kg ha^{-1}) does not further increase yield Nitrogen (N) and Dry Matter Yield although alfalfa fixes atmospheric N via rhizobial symbiosis, supplemental N can be beneficial under certain conditions: Young stands (establishment phase): 20-30 kg N ha^{-1} improves early growth (Lamb *et al*., 2023) Poorly modulated fields: 50 kg N ha^{-1} prevents yield loss (MacAdam, 2023) Mixed grass-legume systems: 10-15 kg N ha^{-1} ton of alfalfa supports growth (Berg *et al*., 2023) Excessive N reduces nodulation efficiency and may decrease forage digestibility due to transformed carbon-to-nitrogen ratios (Dordas, 2023).

Sulfur (S) and Dry Matter Yield Sulfur is crucial for protein synthesis and chlorophyll formation: Deficiency (<10 kg S ha^{-1}): Reduces DMY by 20-30% (Kaiser, 2023) Optimal range (20-30 kg S ha^{-1}): Maximizes protein content and yield (Malhi *et al*., 2023) N: S ratio >11:1 in tissue: Indicates S limitation. Ammonium sulfate is effective S sources that also improve soil structure.

Boron (B) and Dry Matter Yield Boron deficiency is a common constraint in alfalfa production: Optimal B (0.5-1.25 kg ha^{-1}): Enhances DMY by 8-12%. Deficiency symptoms: Stunted growth, yellowing leaves, poor regrowth (Li *et al*., 2023) Toxicity risk (>2 kg ha^{-1}): Causes leaf burn and reduced biomass (Yadav *et al.*, 2023) Foliar B applications (0.2-0.5 kg ha^{-1}) during rapid growth phases are highly effective.

Vermicompost and Dry Matter Yield Vermicompost enhance DMY through multiple mechanisms: 5-10 tons ha^{-1}: Increases yield by 20-35% (Patel *et al*., 2023) 10-15 tons ha^{-1}:

Further improves DMY (12-15 tons ha^{-1}) and soil health (Garg *et al*., 2023) Mechanisms: Improved water retention, microbial diversity, and slow-release nutrient supply (Zhang et al., 2023)

2.6. Effects of Cutting Intervals on Dry Matter Yield and Nutritional Value of Alfalfa

Alfalfa (Medicago sativa) is a highly productive perennial forage legume widely cultivated for its high dry matter yield (DMY) and superior nutritional quality, including crude protein (CP), fiber content, and digestibility (Putnam et al., 2019). The cutting interval (frequency of harvest) significantly influences both yield and nutritional composition, making it a critical management factor in alfalfa production (Sulc and Albrecht, 2020).

Research indicates that longer cutting intervals (e.g., 40–50 days) generally maximize DMY due to extended photosynthetic activity and biomass accumulation (Hintz & Albrecht, 2021). A study by Belanger *et al*. (2020) found that alfalfa harvested at 42-day intervals produced 15–20% higher DMY compared to 28-day intervals. Similarly, in central Ethiopia, Getnet *et al*. (2018) reported that a 35-day cutting interval resulted in significantly greater biomass yield than shorter intervals (21–28 days). However, excessively long cutting intervals (>50 days) may lead to lignification, reducing both forage quality and regrowth potential (Undersander *et al*., 2020). Conversely, very frequent cutting (e.g., 21 days) reduces stand persistence and cumulative seasonal yield due to depletion of root reserves (Teixeira *et al*., 2021)

Shorter cutting intervals (21–28 days) improve forage quality by maintaining higher CP (18–22%) and lower neutral detergent fiber (NDF) and acid detergent fiber (ADF) levels (Adesogan et al., 2019).

However, shorter intervals may compromise total seasonal DMY, requiring a trade-off between yield and quality (Lamb et al., 2021). Sulc and Albrecht (2020) recommend a 30–35-day cutting interval in temperate climates to balance yield and nutritive value, while Hintz and Albrecht (2021) suggest slightly longer intervals (35–42 days) in tropical highlands like Ethiopia to account for slower regrowth

3. MATERIALS AND METHODS

3.1. Description of Study Area

The study was conducted in South Sodo Woreda, in East Gurage Zone, which is located in the Central Ethiopia. The Woreda is located between 8'9'00^0 and 8'19'00^0 latitudes and 38'20'00^0 and 38'36'00^0 longitudes. The woreda covers 220.9 km^2 (SSWAO, 2022). South Sodo Woreda is bordered by Sodo Woreda in the north, Meskan Woreda in the south, and Oromia Region in the east and west. The Woreda is located at a distance of 25 km from Butajera, the capital city of East Gurage zone, 115 km from Hossana, the capital city of the national regional state of Central Ethiopia and 110 km away from the capital city, Addis Ababa. There are seventeen (17) rural kebeles and one (1) town in the Woreda.

The topography of the Woreda consists of a variety of land features. Generally, flat land with a gentle slope comprises 50% of the Woreda. Ups and downs cover about 15%, mountainous valleys 23%, and hilly areas 12% of the Woreda (SSWAO, 2022). The topography's elevation ranges from 1800 meters above sea level (m.a.s.l.) to 3600 m.a.s.l. The mean annual rainfall of the Woreda ranges between 820 mm and 1200 mm. The temperature ranges from 15°C to 27°C, the soil type is 60% brown, 22% black, 12% red, and 6% gray, and the altitudes indicates that 42% is highland and 58% midland (SSWAO, 2022). The population of the Woreda is 56,275, of which 27,155 are male and 29,120 are female (SSWPDO, 2024)

Crop production and livestock husbandry are integral parts of farm activity in South Sodo Woreda. The major crops growing in the Woreda includes cereals (wheat, maize, sorghum, *Teff),* legumes, vegetables, fruit, and *Enset*. Regarding livestock production; cattle, small ruminants (such as goats and sheep), equines, and poultry are the dominant types of livestock kept by farmers. According to the agricultural office of the Woreda, the Woreda has a total livestock population of 225385, of which 31.88% are cattle, 22.4% are small ruminants, 1.55% are horses, 10.16% are donkeys, and 34.01 %t were poultry (SSWAO, 2024). The experimental site Gogati kebele was located 4 km south from Kella town capital of South Sodo district with an altitude of 1800 m.a s.l and 1125 mm of annual rain fall. Soil type is 60% brown, 28% black, and 12% red (SSWAO, 2022). According to Soil fertility map of

SNNPRS which was developed by ATA (2016), soil in the study area has a deficiency of N, P, S and B.

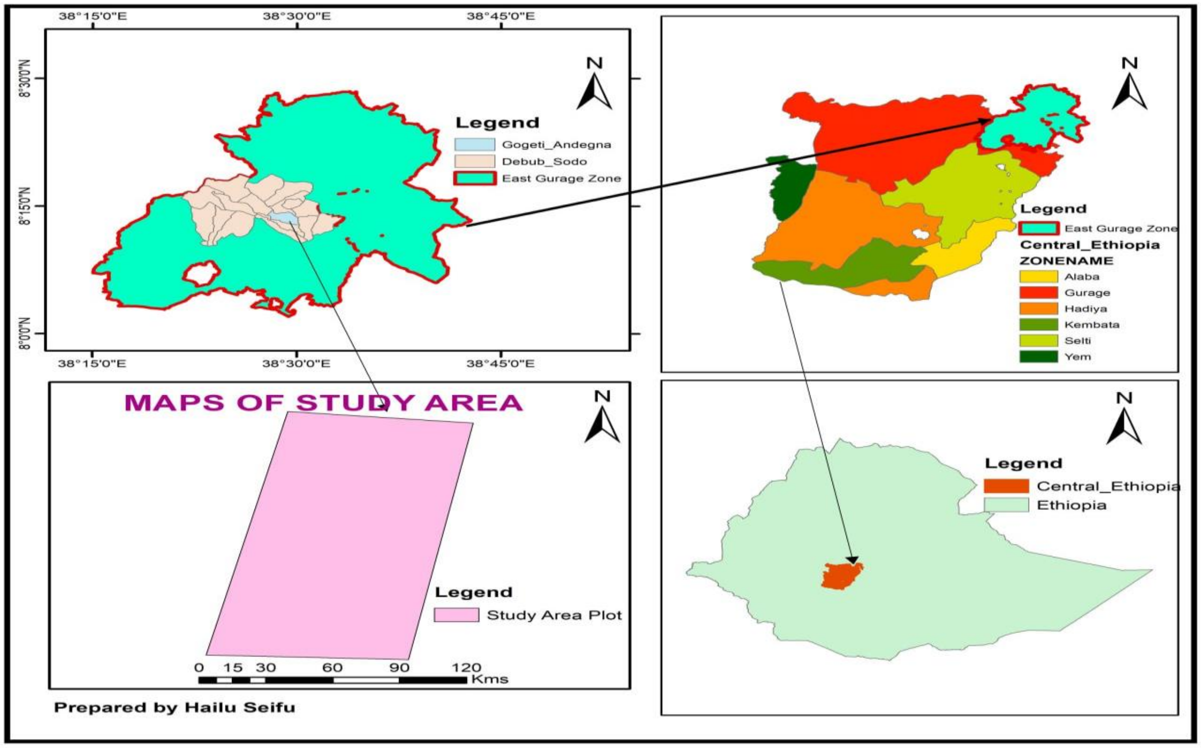

Figure 1 Map of the study area

3.2. Experimental land preparation and treatment

Soil sampling was done before sowing, and samples was taken randomly using an auger in a diagonal pattern from the upper 0-30 cm soil depth in a "X" sampling pattern the entire experimental field and a one composite sample was created by combining them (Hunegnaw. 2019). The collected soil samples were mixed and taken as one composite sample was air-dried and then after drying the coarse particles of the soil have been crushed with mortar and pestle to make fine and easy of grinding. After soil was broken into small crumbs and thoroughly mixed. From this mixture, a composite sample weighing 1 kg was filled into a plastic bag. The soil samples were air-dried in a dust-free environment. For all parameters, except organic carbon and total nitrogen, the samples were sieved through a 2 mm sieve. The samples for organic carbon and total nitrogen determination were ground to pass through a 0.5 mm sieve. The collected soil samples were analyzed at the Soil Laboratory of the

Southern Agricultural Research Institute following standard procedures for selected physico-chemical properties: namely organic carbon, total nitrogen (N), soil pH, available phosphorus (P), available S, available B, cations exchange capacity (CEC) and textural analysis. The particle size distribution of the soil was analyzed using the hydrometer method (Bouyoucos, 1951). The pH of the soil was measured using a digital pH meter in a 1:2.5 soil-to-water ratio (Van Reeuwijk, 1992). Available phosphorus was determined using the Olsen method (Olsen *et al*., 1954), and total nitrogen was determined using the Kjeldahl method (Bremner and Mulvancy, 1982). Organic carbon content was determined using the wet oxidation method (Walkley and Black, 1934), and cation exchange capacity (CEC) was determined using the ammonium acetate saturation method (Chapman, 1965). OM by organic matter was calculated as (OC*1.72) standard methods. Available sulfur was determined using the turbidimetric method, and available boron was determined using spectrophotometric methods (Gupta, 1979). The chemical content of the vermicompost was determined using similar procedures used for the soil. Vermicompost of pH, N, P, S, B, OM, OC, CEC and Texture, from the area was tested.

The tested area was properly cleaned, and after cleaning it was repeatedly plowed with oxen to a fine plow up to three times. Under the right conditions, the soil was crushed to soften it, then, in an east-west direction, a 2 m by 3 m plot was prepared with a 50 cm road left in the middle of each section for management and movement.

3.3. Source of experimental material

A well-known variety of alfalfa (FG-10-09) seed was purchased from Debre Zeit Agricultural Research Center based on its environmental tolerance and productivity. According to the Agricultural Transformation Agency's (ATA, 2016) study, it has been confirmed that NPSB fertilizer was suitable for the study area, and accordingly, NPSB fertilizer was purchased from the farmers' cooperative in the area, whereas vermicompost was purchased from Butajra polytechnic college.

3.4. Experimental design and treatment

Two factors factorial experiment was laid out in a randomized complete block design (RCBD) with 16 treatments (T1: Control (0kg/ha NPSB fertilizer+0 ton/ha vermicompost (VC)), T2: 0 kg/ha NPSB+2.5 ton/ha VC, T3: 0 kg/ha NPSB+5 ton/ha VC, T4: 0 kg/ha NPSB+7.5 ton/ha VC, T5: 50 kg/ha NPSB+0 ton/ha VC, T6: 50 kg/ha NPSB+2.5 ton/ha VC , T7: 50 kg/ha NPSB+5 ton/ha VC, T8: 50 kg/ha NPSB+7.5 ton/ha VC, T9: 100 kg/ha NPSB+0 ton/ha VC, T10: 100 kg/ha NPSB+2.5 ton/ha VC, T11: 100 kg/ha NPSB+5 ton/ha VC, T12: 100 kg/ha NPSB+7.5 ton/ha VC, T13: 150 kg/ha NPSB+0 ton/ha VC, T14:150 kg/ha NPSB+2.5 ton/ha VC, T15: 150 kg/ha NPSB+5 ton/ha VC, T16: 150 kg/ha NPSB+7.5 ton/ha VC) and three cutting intervals (1^{st} cut at 10 week, 2^{nd} cut at 15 week and 3^{rd} cut at 20 week) with three replications and a total of 48 experimental plots and $288m^2$ area covered .

The spacing between each plot was 50cm and in each block was 1 meter. The spacing between the rows was 20 cm. Each plot had a gross plot size of 6 m^2 (2m *3m) which was accommodate fourteen (14) rows per plot. Treatment combination was assigned randomly to each plot by using lottery method

3.5. Fertilizer application and seed sowing

Planting took place on July 20, 2023, which is a common practice in the study area. Vermin composts was sown by random lottery method on each plot at rate of at different rate kg ha^{-1} seven (7) days before planting. The blended NPSB (Nitrogen, Phosphorus, Sulphur and Boron) fertilizer was applied at the time of sowing at different rate on each plot. Alfalfa seeds were sown uniform drilling in rows 20 cm apart at a rate of 20 kg/ha^{-1}, and the soil was covered by hand.

3.6. Management of experimental plot

All the recommended agronomic practice was implemented at uniformly in each treatment such as weed control was done with measured manual weeding to make the forage weed-free to reduce nutrients competition, for the second and third harvests supplementary irrigation was provided every 15 days and fenced to protect the forage from damage by various domestic and wild animals

3.7. Data collection and measurement

For agronomic parameters, fifteen (15) sample plants were randomly selected from randomly selected 3 rows of each plot, and tagged using ID number which was slightly tied on plant to determine various morphological and phonological characteristics and chemical analysis of feed samples was made in first cut.

3.7.1. Phonological data

Phonological data at flowering stage were recorded as follows:

The flowering date: - days of flowering was recorded on each treatment by randomly selecting 3 representative rows at the number of days from the date of planting to the date when 50% of the plants in a plot produced flower (Tibebu *et al.*, 2018).

3.7.2. Growth data parameters

Plant height, primary and secondary branches, number of leaves per plant, number of tiller per plant, and fresh and dry weight of shoots were recorded as follows :

Plant height: - Plant height (cm) was measured using a steel tape at 50% of flowering of the forage starting from the ground level to the highest top leaf of the plant by randomly taking 15 representative samples from each plot (Rayburn *et al.,* 2007).   .

Primary branches: - The number of primary branches per plant was recorded by counting number of branches which develop directly from the main shoot from each treatment by selecting 15 randomly representative plants.

Secondary branches: - The number of secondary branches per plant was recorded by counting the number of branches from each treatment by randomly selecting 15 representative plants.

Number of leaves per plant: - was recorded by counting total number of leaf from each treatment by randomly selecting 15 representative plants on the selected 3 rows in each plot.

Number of tillers per plant: - was recorded by counting visible tillers from each treatment by randomly selecting 15 representative plants on the selected 3 rows in each plot.

Leaf to stem ratio: - was recorded by using 15 randomly selected plants from each plot which was cut above the ground and by partitioning the harvested biomass in to leaf and stem fractions, and drying the fractions. The harvested biomass was manually chopped into small pieces using sickle and a subsample of 500 g was taken and dried in oven at 60°C for 48 hours to determine leaf to stem ratio (Susan *et al*., 2016)

3.8. Biomass yield evaluation

To determine the biomass yield, the forage is collected when it reaches 50% flowering stage (Gzehagne *et al*., 2021). Three randomly selected rows were harvested, and the fresh biomass weight was recorded just after cutting by using sensitive balance. The harvested biomass was manually chopped into small pieces using sickle and a subsample of 500g was taken and dried in oven at 60°C for 48 hours to determine the dry matter yield (DMY).

The following formulas were employed to obtain dry matter yield estimation.

1) Dry matter yield kgha^{-1} = Tot FWx (DWss /HAx EWss) x 10 (Tarawal, 1995)

Where:

Tot FW = total fresh weight from plot in (kg)

DW ss = dry weight of the subsample (grams)

HA = Harvesting area in (m^{2})

FW ss = fresh weight of the subsample (grams)

10 = a constant for conversion of yields kg/m^{2} to ton/ha^{-1}

2) The fresh biomass yield ton/ha^{-1} was determined by using the flowing formula;

$$\text{Fresh biomass yield (ton/ha-}^{1}\text{)} = \frac{\text{Total fresh biomass weight (kg) x10}}{\text{Harvest area in m}^{2}}$$

3) Dry matter (%) was determined by using the following formula

Dry matter (%) = W2-Wp x 100

W1-Wp

Where W2=weight after drying (gram)

W1=fresh weight (gram)

Wp=weight of paper

3.9. Chemical analysis of feed samples

The chemical composition of feed samples was conducted at Hawassa University animal nutrition laboratory. Three randomly selected rows were harvested at each plot, and the feed samples were chopped, properly homogenized, ground to pass through a 1 mm sieve and 500g of representative samples were taken for each treatment. The harvested forage samples were oven dried at 105°C overnight (12 hours) to determine DM and igniting in a muffle furnace at 550 °C for 3 hours for Ash determination. Nitrogen (N) content was determined following the Kjeldahl digestion, distillation, and titration procedures (AOAC, 1995), and the CP was calculated as N x 6.25 (AOAC, 1995). The neutral detergent fiber (NDF), acid detergent fiber (ADF), and Acid detergent lignin (ADL) was analyzed according to Van Soest and Robertson (1985).

3.10. Statistical analysis

The collected data such as dry matter yield and nutritional value were subjected to analysis of variance (ANOVA) using the Statistical Analysis Software System (SAS version 9.4) employing the general linear model (GLM) procedure. The significant difference between treatment means was separated by using the least significant difference (LSD) at a 5% significance level. The following statistical model was used to analyze the data: $Y_{ijk} = \mu + T_i + C_j + Bk + T_i*C_j + \mathbf{\Sigma}_{ijk.}$ Where: Y_{ijk} = individual observation, μ = over all mean, T_i = treatment (fertilizer) effect, C_j=Cuting intervals, B_k = block effect, T_i*C_j = treatment (fertilizer) and cutting intervals interaction effect, $\mathbf{\Sigma}_{ijk}$ = random error

3.11. Economic Analysis

Partial budget analysis was conducted to evaluate the economic benefit of integrated NPSB and vermicompost fertilizers and cutting intervals on alfalfa following the partial budget procedure of CIMMYT (1988). In this analysis, the variable costs were associated with the application of integrated fertilizers. According to South Sodo Districts Farmer's Cooperative association, the cost of NPSB fertilizer was estimated at 3800 ETB per 100 kg per hectare, and the cost of Vermicompost (VC) fertilizer was estimated at 12500 ETB per 5000 kg per hectare at the time of planting.

The selling price per kg of alfalfa on dry matter basis was estimated at 40 ETB which obtained from the Office of Trade and Industry Marketing office of South Sodo Woreda. Additionally, the investment for organic and inorganic fertilizers, labor, and power for performing different operations such as ploughing, weeding and harvesting (cost of labor) were estimated at 150ETB. To reflect the farmer's field yield, the average yield was adjusted downward by 10%, following the approach described by CIMMYT (1988). Net Benefit (NB)= Gross Income (GI)−Total Variable Cost (TVC). The marginal rate of return was calculated by MRR (%) dividing the change in net benefit by the change in variable cost and multiplying the result by 100 as outlined by CIMMYT (1988).

4. RESULTS AND DISCUSSION

4.1. Physico-Chemical Properties of Soil of the Experimental Site

The analytical findings of the top 30 cm deep surface soil at the experimental site before planting indicated that the soil had a pH of 6.3, organic carbon of 2.3%, organic matter of 3.98%, total nitrogen of 0.17%, available phosphorus of 16.52 ppm, and available sulfur of 7.25 ppm, and CEC of 36.56 (meq/100g soil) (Table 4). The pH of prepared vermicompost was 8.1. The soil and vermicompost texture were clay and sandy loam, respectively. According to Landon and Tekalign (1991), pH > 9.0 is very strongly alkaline, 9.0–8.5 is strongly alkaline, 8.4–7.9 is moderately alkaline, 7.8–7.4 is mildly alkaline, 7.3–6.6 is neutral, 6.5–6.1 is slightly acidic, 6.0–5.6 is moderately acidic, 5.5–5.1 is strongly acidic, and below 5.0 is very strongly acidic.

According to this classification, the study site's pre-planting soil had a pH of 6.3, which was slightly acidic. The same authors provided guidelines for soil based on total nitrogen content such as greater than 1.0% is very high, 0.5-1.0% is high, 0.2-0.5% is medium, 0.1-0.2% is low, and less than 0.1% is very low. According to this classification, the total nitrogen content of the soil of the study site (0.17%) was medium. Soil organic carbon concentration was categorized by the same author as extremely low (<0.86), low (0.86-2.59), moderate (2.59-5.17), and high (>5.17). This classification indicates that the study site's OC content of 2.5 % was low.

Available phosphorus in soils was categorized by Tekalign (1991) based on available phosphorus (P) levels as follows: less than 10 ppm is considered low, 11–31 ppm as medium, 32–56 ppm as high, and greater than 56 ppm as very high. In the current study, the total amount of available soil phosphorus was classified as medium (16.52 ppm).

The cation exchange capacity (CEC) of soil is a critical indicator of its ability to retain and supply essential nutrients to plants. Based on widely accepted agronomic guidelines, CEC values can be categorized into different fertility classes. Soils with a CEC of less than 5 cmol(+)/kg are considered very low, indicating poor nutrient retention, typical of sandy or highly weathered soils. A CEC ranging between 5–10 cmol(+)/kg is classified as low, suggesting limited nutrient-holding capacity, often requiring more frequent fertilization. Medium CEC soils (11–20 cmol(+)/kg) are typical of loamy soils with moderate fertility and better nutrient retention. High CEC soils (21–50 cmol(+)/kg) are common in clay-rich or organic-matter-rich soils, which have strong nutrient retention capabilities. Finally, soils with a CEC greater than 50 cmol(+)/kg are classified as very high, often highly organic soils, which may require careful nutrient management to avoid excessive cat ion binding (Hazelton and Murphy, 2016). The current study of the soil in the study area was 36.56 cmo l(+)/kg which indicated high.

The availability of boron (B) in soils is categorized into different fertility classes based on its concentration, which helps guide fertilization practices and prevent deficiencies or toxicities. Soils with less than 0.2 ppm of available boron are classified as very low, indicating a severe deficiency that can limit crop growth, particularly in boron-sensitive plants like legumes (Gupta, 1979). A boron concentration of 0.2–0.5 ppm is considered low, suggesting low adequacy, where supplementation may still be necessary for optimal yields. Soils with 0.6–1.0 ppm boron categorized into the medium range, which is generally sufficient for most crops, though high-demand plants might require additional boron in certain conditions. A high boron level (1.1–2.0 ppm) may a risk for toxicity in sensitive crops, especially in poorly drained or arid soils. Concentrations exceeding 2.0 ppm are classified as very high, carrying a significant risk of boron toxicity, which can obstruct plant growth and may necessitate soil remediation strategies such as leaching or the use of boron-tolerant crop varieties. Thus, the soil of the study area (0.52) had low in available B.

According to Tandon (1991) and Karltun *et al*. (2013), Sulfur (S) is a crucial secondary macronutrient that plays vital roles in plant protein synthesis, chlorophyll formation, and enzyme activation. The availability of sulfur in soils is commonly categorized into different fertility classes to guide proper nutrient management. Soils with less than 5 ppm of available sulfur are classified as very low, indicating severe deficiency that can lead to stunted growth, chlorosis (yellowing of young leaves), and significant yield reduction, particularly in sulfur-sensitive crops like crucifers and legumes. A sulfur concentration of 5-10 ppm is considered low, representing marginal sufficiency where additional sulfur fertilization may be needed for optimal crop performance. The medium range (10-20 ppm) is generally adequate for most crops, though high-yielding varieties or sulfur-demanding plants might still show positive responses to sulfur application. Soils with 20-40 ppm sulfur are classified as high, providing sufficient sulfur for nearly all agricultural crops without requiring supplementation. When sulfur levels exceed 40 ppm, they are considered very high, which may occasionally lead to nutrient imbalances or contribute to soil acidification in certain conditions. Thus, the soil of the study area (7.25) had very low in available S.

According to Brady and Weil (2016) soil organic matter content is a critical indicator of soil health, influencing nutrient cycling, water retention, and crop productivity. Based on established agronomic guidelines, OM levels are categorized as follows: less than 2% organic matter are classified as low, indicating poor fertility status with limited nutrient-holding capacity and weak soil structure - such soils are typically found in intensively farmed systems without organic inputs or in arid regions, and require substantial organic amendments (e.g. compost, manure, or cover crops) to improve productivity.

Soils with 2–4% organic matter are classified as medium, indicating moderate fertility that can support most crops but may benefit from organic amendments to sustain long-term productivity. The high category (4–8% OM) represents soils with robust nutrient-holding capacity and improved structure, typically found in well-managed agricultural systems or natural ecosystems with regular organic inputs. Soils exceeding 8% organic matter are considered as very high, thus, the soil of the study area (3.98) had medium in available OM.

Table 3 Physio-chemical analysis result of soil and vermicompost experimental site before planted of Alfalfa.

Parameters	**pH**	**% OC**	**% OM**	**% TN**	**Av.P (ppm)**	**Av.S (ppm)**	**B (PPM)**	**CEC (meq/100g soil)**	**Texture**
Soil	6.3	2.3	3.98	0.17	16.52	7.25	0.52	36.56	Clay 63%
Vermicompost	8.1	16.4	28.3	1.56	50.8	13.54	0.75	66.45	Sandy Loam 78%

Where VC = Vermicompost; pH = hydrogen power, OC (%), = percent of organic carbon, OM%=organic matter, TN = Percent of total nitrogen, Av.p (ppm) = available P in parts per million, Av. S = A vailabl sulphur, av.B = available Boron, CEC = Cation exchange capacity

4.1.1. Phenological Variables

4.1.2. Days to 50% flowering

The result of integrated NPSB fertilizer and vermicompost application on date of 50% flowering of Alfalfa are shown in Table 4. There were significance difference ($P<0.05$) in 50% flowering date among different treatments in which the earlier 50% flowering date of Alfalfa was recorded in T11 that achieved within 60.21 days whereas the longest days to 50% flowering was recorded in T1 that achieved within 74 days (Table 4).

The current results showed that the integrated rates of NPSB fertilizer and vermicompost application shorten days to 50% flowering of Alfalfa. Early flowering of Alfalfa could be due to the highest rate of NPSB fertilizers and vermicompost application which encourage the fodder in early emerging, rapid growth and development. Several studies demonstrated the significant impact of fertilizer application on flowering time in leguminous crops. Birla *et al*. (2018) found that cowpea plants treated with 100% NPS fertilizer reached 50% flowering earlier than non-fertilized plants, which showed delayed flowering.

The study conducted by Zubair *et al*. (2024) in Mung bean indicated that the integrated application of organic and inorganic nutrients resulted in earlier flowering (34.33 days) compared to the non-fertilized plant (40.00 days). The combination of inorganic fertilizers (45 kg urea/ha + 100 kg NPS/ha + 58 kg MoP/ha) and organic fertilizer (2.5t vermicompost/ha) produced the earliest flowering (31.36 days), whereas unfertilized plants showed delayed flowering (34.10 days) indicating that the balanced fertilization (integration of organic and inorganic nutrient) can significantly accelerate flowering time in legume crops compared to unfertilized legumes (Hossain et al., 2018). Similar results are also reported by Aslam *et al* (2024) who reported significant variations in days to flowering of Mung bean due to the integrated application of organic and inorganic nutrients.

Table 4 Effects of integrated NPSB and vermicompost fertilizers and cutting intervals on the Phenological and growth parameters

Integrated NPSB and Vermicompost Fertilizers	Phenological and growth parameters		
	Flowering Days	PLH (cm)	TLN
First Cutting Interval			
Control (0kg NPSB + 0t/ha VC)	74[a]	63.37[g]	10.57[f]
0kg NPSB + 2.5 t/ha VC	71[ab]	72.13[f]	12.33[ef]
0 kg NPSB + 5 t/ha VC	69[bcd]	76.50[def]	15.17[cdef]
0kg NPSB + 7.5 t/ha VC	69.33[abc]	80.53[cd]	15.30[cdef]
50kg NPSB + 0 t/ha VC	68.60[bcd]	73.47[ef]	15.70[bcde]
50 NPSB + 2.5 t/ha VC	68[bcd]	86.63[cd]	14.40[cdef]
50kg NPSB + 5 t/ha VC	67.93[bcd]	84.77[abc]	18.60[bcd]
50kg NPSB + 7.5 t/ha VC	65[cdef]	80.60[cd]	16.07[bcde]
100kg NPSB + 0 t/ha VC	67.33[bcd]	82.73[bcd]	13.70[edf]
100kg NPSB + 2.5 t/ha VC	66.33[bde]	79.37[cde]	16.50[bcde]
100kg NPSB + 5 t/ha VC	60.21[f]	88.17[ab]	29.10[a]
100 kg NPSB + 7.5 t/ha VC	64.16[def]	82.10[bcd]	13.03[ef]
150kg NPSB + 0 t/ha VC	68.16[bcd]	82.27[bcd]	18.80[bc]
150 kg NPSB + 2.5 t/ha VC	66.33[bcde]	78.00[cdef]	20.43[b]
150kg NPSB + 5 t/ha VC	65.13[cdef]	81.17[cd]	17.07[bcde]
150 kg NPSB + 7.5 t/ha VC	61.66[ef]	90.77[a]	28.47[a]
Mean ± SE	67 ± 0.85	80.16 ± 1.6[c]	17.20 ± 1.29[c]
P-values			
NPSB* VC	0.0007	<0.0001	<0.0001
Cutting interval		<0.0001	<0.0001
NPSB*VC*cutting interval		0.003	0.001
Second Cutting Interval			
Control (0kg NPSB + 0t/ha VC)		65.17[f]	10.9[f]
0kg NPSB + 2.5 t/ha VC		75.1[e]	12.6[ef]
0kg NPSB + 5 t/ha VC		79.76[de]	14.6[cdef]
0kg NPSB + 7.5 t/ha VC		82.86[bcd]	15.967[cde]
50kg NPSB + 0 t/ha VC		75.23[e]	15.9[cde]
50kg NPSB + 2.5 t/ha VC		82.3[cd]	14.37[cdef]
50kg NPSB + 5 t/ha VC		86.6[abc]	17.133[bcde]
50kg NPSB + 7.5 t/ha VC		82.56[cd]	16.1[cde]
100kg NPSB + 0 t/ha VC		84.03[bcd]	14.3[cdef]
100kg NPSB + 2.5 t/ha VC		81.43[cde]	17[bcde]
100 kg NPSB + 5 t/ha VC		89.46[ab]	29.6[a]
100kg NPSB + 7.5 t/ha VC		83.9[bcd]	13.73[def]
150kg NPSB + 0 t/ha VC		84.26[bcd]	18.53[bc]
150kg NPSB + 2.5 t/ha VC		80.03[cde]	21.23[b]

150kg NPSB + 5 t/ha VC	83.87^{bcd}	17.83^{bcd}
150kg NPSB + 7.5 t/ha VC	92.43^{a}	28.2^{a}
Mean ± SE	$81.81+1.57^{b}$	$17.37+1.28^{b}$
P-values		
NPSB* VC	<.0001	<.0001
Cutting interval	0.007	0.001
NPSB*VC*cutting interval	0.001	0.005
Third Cutting Interval	3rd cut	3rd cut
Control (0kg NPSB + 0t/ha VC)	67.7^{f}	13.26^{f}
0kg NPSB + 2.5 t/ha VC	76.96^{e}	14.83^{ef}
0kg NPSB + 5 t/ha VC	81.8^{cde}	18.33^{cde}
0kg NPSB + 7.5 t/ha VC	85^{bcd}	17.83^{cdef}
50kg NPSB + 0 t/ha VC	77.7^{de}	18.36^{cde}
50kg NPSB + 2.5 t/ha VC	84.83^{bcd}	17.06^{cdef}
50kg NPSB + 5 t/ha VC	88.76^{abc}	20^{bcde}
50kg NPSB + 7.5 t/ha VC	85.23^{bcd}	18.36^{cde}
100kg NPSB + 0 t/ha VC	86.53^{bc}	16.33^{cdef}
100kg NPSB + 2.5 t/ha VC	83.7^{cde}	18.86^{cde}
100kg NPSB + 5 t/ha VC	92.1^{ab}	31.7^{a}
100kg NPSB + 7.5 t/ha VC	86.93^{abc}	15.46^{def}
150kg NPSB + 0 t/ha VC	86.66^{bc}	21.26^{bc}
150kg NPSB + 2.5 t/ha VC	81.86cde	23.8^{b}
150kg NPSB + 5 t/ha VC	85.53^{bc}	20.2^{bcd}
150kg NPSB + 7.5 t/ha VC	94.46^{a}	30.93^{a}
Mean ± SE	$84.11+1.57^{a}$	$19.79+1.29^{a}$
P-values		
NPSB* VC	<.0001	<.0001
Cutting interval	0.001	0.001
NPSB*VC*cutting interval	0.002	0.001

*Different superscript letters within the same column indicate significant differences between treatments at P < 0.05. T1: Control (0kg/ha NPSB fertilizer+0 ton/ha vermicompost (VC)); T2: 0 kg/ha NPSB+2.5 ton/ha VC; T3: 0 kg/ha NPSB+5 ton/ha VC; T4: 0 kg/ha NPSB+7.5 ton/ha VC; T5: 50 kg/ha NPSB+0 ton/ha VC; T6: 50 kg/ha NPSB+2.5 ton/ha VC ; T7: 50 kg/ha NPSB+5 ton/ha VC; T8: 50 kg/ha NPSB+7.5 ton/ha VC; T9: 100 kg/ha NPSB+0 ton/ha VC; T10: 100 kg/ha NPSB+2.5 ton/ha VC; T11: 100 kg/ha NPSB+5 ton/ha VC; T12: 100 kg/ha NPSB+7.5 ton/ha VC; T13: 150 kg/ha NPSB+0 ton/ha VC; T14:150 kg/ha NPSB+2.5 ton/ha VC; T15: 150 kg/ha NPSB+5 ton/ha VC; T16: 150 kg/ha NPSB+7,5 ton/ha VC; PV (Probability Value); T * CI=interaction between treatment (fertilizer) and cutting interval, PLH= Plant Height, TLN= Number of Tillers per Plant: ;**(highly significant)*

4.2. Growth Parameter

4.2.1. Plant Height

The analysis of variance showed that plant height of Alfalfa was significantly (P<0.05) affected by the integrated application of NPSB fertilizer and vermicompost, and cutting intervals. Among the treatments, the mean tallest plant height was recorded T16 (92.55 cm) whereas the mean shortest plant height was observed in control T1 (65.41cm). Plant height increased with the increased rate of integrated NPSB fertilizer and vermicompost, and increased cutting intervals. The overall mean plant height T16 was 29.33% higher than T1. The current result showed that the highest Alfalfa height was recorded when equal proportion of both fertilizers (NPSB fertilizer and vermicomposts) was used while the lowest Alfalfa height was indicated at non NPSB fertilizer and vermicompost application.

Plant height (PLH) of alfalfa was significantly influenced by treatment and cutting intervals, with highly significant differences observed across all cuts (P < 0.001). Mean PLH values progressively increased from the first to the third cut, measuring 80.16 cm, 81.81 cm, and 84.11 cm, respectively. This trend demonstrates a consistent increase in plant height with successive harvests, reflecting alfalfa's strong regrowth capacity. Particularly, the third cut was significantly (P < 0.001) higher than the first and second cuts by 5% and 2.75%, respectively. The observed growth can be attributed to factors such as improved nutrient uptake, greater tillering, and enhanced shoot elongation, all of which are supported by optimal nutrient availability. The high level of significance (P < 0.001) across cutting intervals highlights the strong influence of cutting management on plant height. This finding aligns with previous studies conducted by Geleti *et al*. (2014), Din *et al*. (1993), and Wayu and Atsbeha (2019), which also reported similar trends regarding the effects of cutting management on alfalfa growth which used to photosynthesis to shoot regeneration, leading to taller regrowth rapid cell division and stem elongation (Wayu and Atsbeha., 2019).

The mean plant height in the current study was higher than the finding reported by Dinkale (2023) who reported the mean plant height of 78.95 cm for Alfalfa forage in West Hararghe Zone, Oromia and 77.24cm; Geleti *et al*., (2014). In similar fashion, the plant height lower than of 92 cm are also reported by Denbela *et al*. (2015) in Jinka Agricultural Research

Center and Workiye *et at*., (2021) in alfalfa under rain fed condition. The differences between different studies and current study might be due to different management system, type of fertilizer used and agro-ecology conditions.

Kebede *et al*. (2017) also reported that application of fertilizers influences the height of alfalfa. The integrated fertilization of vermicompost and chemical fertilizer has a major effect on plant height of mung bean in which the highest plant height was recorded in NPK 100kg + compost group than non-fertilized ones (Fouda *et al*. (2017). This is due to vermicompost contains a combination of macro- and micro-nutrients and has a positive effect on plant nutrition, growth, photosynthesis and chlorophyll content of the leaves (Rekha *et al*. 2018). The study conducted by Ayele (2023) by using the combined application rate of 100kg ha^{-1} NPS with 4 t ha^{-1} VC rate resulted the tallest plant height (33.37 cm) compared to the shortest plant height of 22.86 cm of Mung bean when no fertilizers was used. The increase in plant height with the increased rates of NPS fertilizer and VC might be due to the fact that nitrogen, phosphorous and sulfur nutrients involved in vital plant functions and enhanced plant growth and so as plant height (Ayele, 2023). This indicates a maximum vegetative growth of the plants under higher N, P and S availability which plays a pivotal role in early root growth which in turn increases the nutrient up take of the plant. Application of vermicompost, which has rich source of nutrients, vital plant promoting and humus forming substances, N-fixers and other beneficial micro-organisms helped for building up of cells, thus better growth (Desai, 2018).

4.2.2. Number of Tillers per Plant

The number of tillers per plant was significantly influenced ($P<0.05$) by application of integrated NPSB fertilizer and vermicompost, and cutting intervals in which the highest tiller count was observed in T11 whereas the lowest tillers per plant was observed in control group (T1). Among the treatments, the mean highest tiller count was recorded T11 (30.13) whereas the mean lowest tiller count was observed in control T1 (11.58 number of tillers per plant increased with the increased rate of integrated NPSB fertilizer and vermicompost, and increased cutting intervals. The overall mean plant height T11 was 61.57% higher than T1.

Cutting intervals highly significant (P<0.001) effect the number of tillers per plant of alfalfa. The mean value of alfalfa 47.25, 57.81, and 66.53 for the first, second, and third cuts, respectively. The third cut was highly significantly (<0.001) higher than by 13.09% and 12.23% compared to the first and second cuts respectively, These results suggest that alfalfa tillers increase cutting intervals increase when combined application of fertilizer.

Moreover, the observed yield increases across cutting. The current findings align with previous research by Kizima *et al*. (2014), which demonstrated that appropriate nitrogen fertilization levels significantly influence tiller development and population dynamics in Cenchrus ciliaris grown in Morogoro, Tanzania. These results further corroborate the work of Mushtaque *et al*. (2010), who found that nitrogen application stimulates dormant bud growth and promotes denser vegetative stands by enhancing tiller regeneration rates in Buffel grass (Cenchrus ciliaris Linn.), and also Rambau *et al*. (2016) who reported for Napier grass shows, the number of tillers increased with increase maturity of the Napier grass.

4.2.3. Number of Primary Branches in Alfalfa

The analysis of variance showed that number of primary branches of alfalfa was significantly (P<0.05) affected by the integrated NPSB fertilizer and vermicompost, and cutting intervals in which T11 produced the highest number of primary branches per plant whereas control (T1) produced the lowest number of primary branches per plant (Table 5). The mean number of primary branches count was recorded T11 (22.52) whereas the mean lower branches count was observed in control T1 (14.81) numbers of branches per plant increased with the increased rate of integrated NPSB fertilizer and vermicompost, and increased cutting intervals. The overall mean number of primary branches T11 was 34.24% higher than T1.

This might be due to optimal supply of NPSB and verimicompost in the early stage of plant growth which enhanced the plant growth in T11 and lack of the available growth resources and more competition of the limited nutrition resources for branching in T1. In other words, the possible reason for the lower number of primary branches per plant T1 might be due to the fact that the legumes require NPSB and vermicomopst for optimal symbiotic performance. The study conducted by Ayele, (2023) also indicated the highest number of primary branches per plant (11.4) when 100 kg NPS ha^{-1} and 4 t ha^{-1} VC fertilizer rate is used and the lowest number of primary branches per plant (6.53) is recorded without the use of fertilizers in Mung bean.

The increase in number of primary branches per plant with the increased rates of NPS fertilizer and vermicompost might be due to the involvement of nitrogen; phosphorus and sulfur nutrients which enhanced growth in the branch of the crop. The increase in number of primary per plant in response to the increased NPS application rate indicates maximum vegetative growth of the plants under higher N and S availability since it is vital in early root propagation and increases the nutrient up take of the plant and so as resulting in increased vegetative growth. The study conducted by Elka *et al*. (2020) also reported the increased primary and secondary branches due to the increased in vermicompost and NPS fertilizer rates.

Cutting intervals highly significant (P<0.001) effect the number of primary branches in Alfalfa. The mean value of alfalfa 16.38, 17.99, and 19.78 for the first, second, and third cuts, respectively. The third cut was highly significantly (<0.001) higher than by 17.19% and 9.05% compared to the first and second cuts, respectively, These results suggest that alfalfa branch number increase cutting intervals increase when combined application of fertilizer. Moreover, the observed yield increases across cutting.

The mean PB obtained in the present finding was 18.05 which is lower than the results of Desai (2018) who reported the mean 25 in Karnataka when 150kg NPK + 2.5t/ha vermicompost + Rhizobium was applied and higher than Aslam et al, (2024) 2tone vermicompost +20kg N and 60kg P the mean value was 7.66. The reason for this variation might be due to different management system, soil type, agronomic season, and fertilizer type and agro-ecological variations.

4.2.4. Number of Secondary Branches of Alfalfa

The analysis of variance showed that the number of secondary branches of Alfalfa was significantly (P<0.05) influenced by the integrated use of NPSB fertilizer and vermicompost, and cutting intervals. The highest secondary branches were recorded in T11 whereas the lowest secondary branches were recorded in T1 (control). In agreement with the current result, Ayele (2023) reported that the highest number of secondary branches per plant (9.08) was recorded in100 kg ha^{-1} NPS fertilizer and 4 t ha^{-1} VC rates, which is statistically apart from 100 kg ha^{-1} NPS fertilizer rate.

The increase in number of secondary branches per plant with the increased rates of NPS fertilizer and vermicompost might be due to nitrogen; phosphorus and sulfur nutrients which enhanced the growth in the branch of the crop. Similar result also reported by Elka et al. (2020) who found the increased secondary branches of plant due to increased vermicompost and NPS fertilizer rates. Cutting intervals had highly significant (P<0.001) effect on the number of primary branches in Alfalfa. The mean value of alfalfa 33.57, 36.40, and 38.15 for the first, second, and third cuts, respectively. The third cut was highly significantly (<0.001) higher than by 12.01% and 4.59% compared to the first and second cuts, respectively, These results suggest that alfalfa branch number increase cutting intervals increase when combined application of fertilizer.

Table 5 Effect of integrated use of NPSB fertilizer and vermicompost, and cutting intervals on primary branch, secondary branch, number of leaf per plant and leaf to stem ratio

Integrated NPSB and Vermicompost Fertilizers	Growth parameters			
	PB	SB	LFN	LSR
First Cutting Interval				
Control (0 NPSB + 0 VC)	12.12^{e}	18.37^{f}	410^{g}	0.79^{h}
0 NPSB + 2.5 t/ha VC	14.20^{de}	31.50^{cde}	422.5^{fg}	0.84^{fg}
0 NPSB + 5 t/ha VC	16.67^{bcd}	36.50^{bcde}	420.6^{fg}	0.87^{f}
0 NPSB + 7.5 t/ha VC	16.05^{cde}	35.57^{bcde}	483.9^{e}	0.82^{g}
50 NPSB + 0 t/ha VC	14.13^{de}	30.75^{cde}	440.3^{f}	0.91^{e}
50 NPSB + 2.5 t/ha VC	15.80^{cde}	32.43^{cde}	501.3^{e}	0.92^{de}
50 NPSB + 5 t/ha VC	15.91^{cde}	28.37^{e}	512.9^{e}	0.92^{de}
50 NPSB + 7.5 t/ha VC	16.67^{bcd}	38.37^{abc}	552.8^{c}	0.95^{d}
100 NPSB + 0 t/ha VC	17.20^{bcd}	28.90^{e}	497.3^{e}	0.85^{fg}
100 NPSB + 2.5 t/ha VC	14.57^{de}	33.16^{bcde}	560.1^{d}	1.01^{c}
100 NPSB + 5 t/ha VC	21.43^{a}	46.63^{a}	670^{a}	1.07^{a}
100 NPSB + 7.5 t/ha VC	15.67^{cde}	38.03^{bc}	573.6^{c}	1.02^{bc}
150 NPSB + 0 t/ha VC	18.06^{abcd}	37.50^{bcd}	502.8^{e}	0.86^{f}
150 NPSB + 2.5 t/ha VC	14.27^{de}	29.10^{de}	559.6^{d}	0.92^{de}

150 NPSB + 5 t/ha VC	18.73^{abc}	30.63^{cde}	599.6^{c}	0.94^{d}
150 NPSB + 7.5 t/ha VC	20.57^{ab}	41.27*ab*	669.5^{b}	1.05^{ab}
Mean ± SE	16.38 ± 0.61^{c}	33.57 ± 1.61^{c}	523.6 ± 20.2^{c}	0.92 ± 0.021^{c}
P-values				
NPSB* VC	0.0036	<.0001	<.0001	<.0001
Cutting interval	0.001	0.001	0.001	0.011
NPSB*VC*cutting interval	<.0001	<.0001	0.001	0.001
Second Cutting Interval				
Control (0 NPSB + 0 VC)	15.27^{d}	22.43^{f}	420^{g}	0.92^{e}
0 NPSB + 2.5 t/ha VC	16.23^{cd}	32.33^{cdef}	434.4^{g}	0.95^{de}
0 NPSB + 5 t/ha VC	18.77^{abcd}	37.43^{bcde}	429.2^{g}	0.97^{d}
0 NPSB + 7.5 t/ha VC	18.57^{abcd}	35.70^{bcde}	547.6^{f}	0.94^{de}
50 NPSB + 0 t/ha VC	15.70^{cd}	32.07^{cdef}	443.3^{g}	1.026^{c}
50 NPSB + 2.5 t/ha VC	17.63^{bcd}	34.97^{bcde}	569.3^{ef}	1.04^{c}
50 NPSB + 5 t/ha VC	17.53^{bcd}	31.17^{def}	587.8^{e}	1.04^{c}
50 NPSB + 7.5 t/ha VC	19.17^{abcd}	43.80^{abc}	721.8^{c}	1.06^{c}
100 NPSB + 0 t/ha VC	19.27^{abc}	39.40^{abcde}	569.3^{ef}	0.96^{de}
100 NPSB + 2.5 t/ha VC	15.83^{cd}	33.70^{cdef}	653.8^{d}	1.13^{b}
100 NPSB + 5 t/ha VC	22.43^{a}	46.63^{a}	740^{a}	1.186^{a}
100 NPSB + 7.5 t/ha VC	17.03^{bcd}	41.53^{abcd}	720.8^{c}	1.13^{b}
150 NPSB + 0 t/ha VC	19.47^{abc}	50.30^{a}	573.3^{ef}	0.94^{de}
150 NPSB + 2.5 t/ha VC	15.23^{d}	29.20^{ef}	659.8^{d}	1.047^{c}
150 NPSB + 5 t/ha VC	20.33^{ab}	36.07^{bcde}	734.3c	1.053^{c}
150 NPSB + 7.5 t/ha VC	19.30^{abc}	35.67^{bcde}	693.8b	1.153^{ab}
Mean ± SE	17.99 ± 0.51^{b}	36.40 ± 1.72^{b}	593.6± 28.9b	1.036 ± 0.021^{a}
P-values				
NPSB* VC	0.0016	0.0072	<.0001	<.0001
Cutting interval	0.001	0.001	0.002	0.003
NPSB*VC*cutting interval	<.0001	<.0001	0.001	0.002
Third Cutting Interval				
Control (0 NPSB + 0 VC)	17.03de	24.93e	466g	0.87e
0 NPSB + 2.5 t/ha VC	18.36bcde	35.06cde	493.9g	0.92d
0 NPSB + 5 t/ha VC	21.1abcd	40.7abcd	482.6g	0.95d
0 NPSB + 7.5 t/ha VC	20.57abcde	39.33abcd	638.4f	0.91de
50 NPSB + 0 t/ha VC	17de	33.86cde	519.1g	1.00c
50 NPSB + 2.5 t/ha VC	19.3bcde	36.66bcd	685.4ef	1.01c
50 NPSB + 5 t/ha VC	18.9bcde	32.86cde	704e	1.01c
50 NPSB + 7.5 t/ha VC	20abcde	46.86ab	883.8c	1.04c
100 NPSB + 0 t/ha VC	20.4abcde	41.6abcd	674ef	0.94d
100 NPSB + 2.5 t/ha VC	18.06cde	35.33bcde	796.9d	1.09b
100 NPSB + 5 t/ha VC	23.7a	49.83a	890a	1.157a
100 NPSB + 7.5 t/ha VC	18.93bcde	43.57abc	882.9c	1.11b

150 NPSB + 0 t/ha VC	22.13abc	41.46bcd	686ef	0.94d
150 NPSB + 2.5 t/ha VC	16.5e	31.27de	797.1d	1.01c
150 NPSB + 5 t/ha VC	22.36ab	39abcd	748.6c	1.02c
150 NPSB + 7.5 t/ha VC	22.06abc	38.03ab	850.9b	1.13ab
Mean ± SE	19.78±0.53a	38.15±1.53a	700± 37a	1.007±0.021b
P-values				
NPSB* VC	0.0294	0.023	<.0001	<.0001
Cutting interval	0.001	0.001	0.012	0.001
NPSB*VC*cutting interval	<.0001	<.0001	0.001	0.001

*Different superscript letters within the same column indicate significant differences between treatments at P < 0.05 (based on a statistical test such as LSD). T1: Control (0kg/ha NPSB fertilizer+0 ton/ha vermicompost (VC)); T2: 0 kg/ha NPSB+2.5 ton/ha VC; T3: 0 kg/ha NPSB+5 ton/ha VC; T4: 0 kg/ha NPSB+7.5 ton/ha VC; T5: 50 kg/ha NPSB+0 ton/ha VC; T6: 50 kg/ha NPSB+2.5 ton/ha VC ; T7: 50 kg/ha NPSB+5 ton/ha VC; T8: 50 kg/ha NPSB+7.5 ton/ha VC; T9: 100 kg/ha NPSB+0 ton/ha VC; T10: 100 kg/ha NPSB+2.5 ton/ha VC; T11: 100 kg/ha NPSB+5 ton/ha VC; T12: 100 kg/ha NPSB+7.5 ton/ha VC; T13: 150 kg/ha NPSB+0 ton/ha VC; T14:150 kg/ha NPSB+2.5 ton/ha VC; T15: 150 kg/ha NPSB+5 ton/ha VC; T16: 150 kg/ha NPSB+7,5 ton/ha VC; PV (Probability Value); LFN (on number of leaf per plant); LSR(leaf to stem ratio); **(highly significant; *** very highly significant*

4.2.5. Number of Leaves per Plant

The analysis of variance showed that the number of leaves per plant was significantly (P<0.05) affected by the integrated use of NPSB fertilizer and vermicompost and cutting intervals (Table 7). The highest number of leaf per plant was recorded in T11 while the lowest number of leaf per plant was recorded in T1 (control). The mean of T11 showed a 43.66% leaf per plant over the mean of T1. The current study indicated that the number of leaf per plant was increased when equal proportion of NPSB fertilizer and vermicompost was used and vice versa which is in line with the study conducted by Desai (2018) who reported the maximum number of leaves per plant (44.26) when 5t/ha of Vermicompost and 30:40:37.50 kg NPK/ha was used. The increased number of leaves per plant might be due to the supply of nutrients from both organic and inorganic fertilizers which enhanced the metabolic activity of plant by increasing cell division and cell elongation (Patil *et al*., 2014).

The leaf number (LFN) of alfalfa was influenced by both the cutting intervals and fertilizer treatments as shown highly significant (P < 0.0001) across all three cutting interval. The third cut was highly significantly (<0.001) higher than by 25.2% and 15.2% compared to the first and second cuts, respectively, The overall mean LFN progressively increased from 523.6 in the first cut to 593.6 in the second, reaching the highest value of 700 in the third cut. The LFN at the third cut was higher (<0.001) by 25.2% and 15.2% compared to the first and second cuts, respectively. This report agreed with Molla 2018 and berhanu., 2007 in vetch legumes in fogera district northwest Ethiopia.

This increasing indicates that alfalfa has strong regrowth potential and continues to develop more leaf with successive harvests, particularly when managed under integrated fertilizer amount. The increase in LFN over successive cuts and the higher showed of treatments with integrated fertilizer application highlight the importance of effective fertilization in supporting leaf development. The mean of LFN obtained in the current study was all cuts 738 higher than the results of Desai (2018) who reported that, cuts 217.07 in Karnataka. The variation this might be due to differences in agro-ecology, different management system, soil type

4.2.6. Leaf-to-Stem Ratio (LSR) of Alfalfa

The leaf-to-stem ratio (LSR) of alfalfa was significantly (P<0.05) influenced by the application of integrated NPSB fertilizer and vermicompost, and cutting intervals in which the highest LSR was recorded in T11 and the lowest LSR was observed in control (T1) The mean of T11 showed a 24.57% leaf-to-stem ratio over the mean of T1 (Table 6). A balanced application of integrated NPSB fertilizer and vermicompost (T11) leads to a higher leaf-to-stem ratio however a lower proportion of NPSB and vermicompost reduced LSR. The mean LSR observed in the current study was higher than 0.63 reported by Gleti *et al*. (2014) reported in cool sub moist agro-ecology of Ethiopia and lower than 1.01 reported by Gezahegn *et al*. (2017) in central highland of Ethiopia. The differences in different studies might be due to differences in agro-ecology, types of fertilizer, harvesting stage and management practices.

cutting intervals highly significant (P<0.001) effect the leaf.to steam ratio in alfalfa. The mean value of alfalfa 0.92, 1.036, and 1.007 for the first, second, and third cuts, respectively. The second cut was highly significantly (<0.001) higher than by 11.2% and 2.8% compared to the first and third cuts, respectively. This report quite agreed with Geleti *et al*. (2014), Gashaw *et al*. (2015), in alfalfa Molla, (2018), Berhanu, (2007) vetch in fogera district northwest Ethiopia. Leaf- to- stem ratio increase in second cut then decreases in third cut the reason might be the loss of leaves as the plant become matured. According to Kebede, *et al*, (2017) (Afsharamanesh, 2009; Diriba *et al* (2014). The leaves to stem ratio, which varied depending on the number of cuts, harvest cycles and harvest stage, is an important quality indicator during evaluation of herbage quality. Leaf to stem ratio is an important trait in the selection of appropriate forage cultivar as it is strongly related to forage quality (Diriba *et al*., 2014).

4.3. Fresh Biomass Yield (FBY) of Alfalfa

The analysis of variance showed that fresh biomass yield (FBY) of alfalfa was significantly ($P<0.05$) affected by integrated application of NPSB fertilizer and vermicompost, and cutting intervals (Table 7) with the highest fresh biomass yield (FBY) was recorded in T11 and the lowest fresh biomass yield was recorded in control (T1). Fresh biomass yield of Alfalfa was enhanced when equal proportions of NPSB fertilizer and vermicompost was applied and decreased with the decreased proportion of NPSB fertilizers and vermicompost. The mean fresh biomass yield observed in the current study was higher than the mean (37.95 t/ha) reported by Turan, (2017) in Turkey and lower than the means (66.78 t/ha and 78.16 t/ha) reported by Tucak, (2020) and Alemu *et al* (2020), respectively. The variation between different studies might be due to differences in agro-ecology, types of fertilizer, variety, harvesting stage and management practices. Amending the soil by vermicompost and inorganic fertilizers enhanced the shoot, leaf canopy area of the plant, and achieved higher shoot dry weight of leaf (Bajracharya *et al*., 2007).

Cutting intervals had significantly higher ($P<0.001$) effect on the fresh biomass yield of alfalfa. The mean value of alfalfa 47.25, 57.81, and 66.53 for the first, second, and third cuts, respectively. The third cut was highly significantly (<0.001) higher by 29% and 13.11% compared to the first and second cuts, respectively, These results suggest that alfalfa continues to accumulate biomass effectively through multiple harvests when combined with application of fertilizer. Moreover, the observed yield increases across cutting intervals reflect the strong regrowth potential of alfalfa under integrated fertilizer management (Vijay et al., 2015), this can be due to the leguminous plant, which supports improved fresh biomass yield through rapid tissue expansion, increased tiller formation, leaf elongation, and stem development as the number of cutting intervals increases.(Vishal and Duhan , 2013) and Raju *et al.* (2014).

4.4. Dry Matter Yield (DMY)

The analysis of variance showed that DMY of Alfalfa was significantly ($P<0.05$) affected by the integrated application of NPSB fertilizer and vermicompost, and cutting intervals in which the highest dry matter yield was obtained from T11 and the lowest DMY was obtained from plots treated with (T1) (Table 6). The DMY was highest when equal proportion of NPSB fertilizer and vermicompost was used and declined as the proportion of both decreased. This might be due to the amendment of soil when both vermicompost and NPSB fertilizers was used which enhanced the growth parameters such as plant height, leaf length, tillers numbers, shoot, and leaf canopy area of plant and so as higher dry matter yield (Bajracharya *et al*., 2007). Uptake of nutrients such as nitrogen (N), phosphorus (P), potassium (K) and magnesium (Mg) by the plant was increased when applied with vermicompost and which in turn enhances the growth parameters and tiller number of plant (Ibrahim *et al*., 2016). Singh *et al*. (2016) also reported the enhancement of growth parameters such as tiller number, plant height, shoot and canopy of the leaf due to addition of vermicompost which in turn increases the proportion of leaf to stem ration and DMY.

The mean dry mater yield observed in the current study was higher than the 3.23 t/ha, 2.16 t/ha and 6.5t/ha reported by Awad *et al*. (2009), Afsharmanesh (2009) and Gezahegn *et al* (2017), respectively, and lower than the mean 10.88t/ha and 11t/ha reported by Denbela (2015) and Zeinab *et al* (2013), respectively. The variations between different studies might be due to differences in agro-ecology, types of fertilizers, variety, harvesting stage and management practice.

Similar to fertilizer application cutting intervals had a highly significant ($P < 0.001$) effect on the dry matter yield (DMY) of alfalfa. The mean DMY values across the three cuts were 7.22, 8.62, and 9.89 t/ha for the first, second, and third cuts, respectively. This result demonstrates a consistent increase in biomass yield with each successive harvest. Specially, the third cut showed a 27% increase over the first cut and a 12.85% increase over the second cut. These increases suggest that alfalfa exhibits strong regrowth ability when managed under favorable conditions, particularly with the application of integrated fertilizers. The first harvest had lower dry mater yield than the second and the third might be due to the early establishment phase while subsequent cuttings resulted in higher yields which is in line with the study reported by Wayu and Atsbha (2019).both cutting stage and fertilizer treatment significantly influenced dry matter yield in alfalfa. Yield increased progressively from the first to third cut, and treatments with integrated fertilizer application consistently produced higher yields (Obsa *et al*, 2017; (Wayu, and Atsbha, 2019)

Table 6 Effect of integrated application of NPSB fertilizer and vermicompost, and cutting intervals on fresh biomass yield and dry matter yield

Integrated NPSB and Vermicompost Fertilizers	Biomass yield	
	FBY	**DMY**
First Cutting Interval		
Control (0 NPSB + 0 VC)	35.07^{d}	5.44^{e}
0 NPSB + 2.5 t/ha VC	38.82^{cd}	5.66^{de}
0 NPSB + 5 t/ha VC	40.62^{cd}	6.47^{cde}
0 NPSB + 7.5 t/ha VC	42.1^{cd}	6.44^{cde}
50 NPSB + 0 t/ha VC	42.82^{cd}	6.81^{bcde}
50 NPSB + 2.5 t/ha VC	44.267^{bcd}	7.16^{bcd}
50 NPSB + 5 t/ha VC	43.97^{cd}	6.64^{bcde}
50 NPSB + 7.5 t/ha VC	48.043^{abcd}	7.45^{abc}
100 NPSB + 0 t/ha VC	42.17^{cd}	6.42^{cde}
100 NPSB + 2.5 t/ha VC	52.64^{abc}	7.76^{abc}
100 NPSB + 5 t/ha VC	60.55^{a}	9.03^{a}
100 NPSB + 7.5 t/ha VC	49.69^{abcd}	8.09^{ab}
150 NPSB + 0 t/ha VC	49.18^{abcd}	7.38^{bc}
150 NPSB + 2.5 t/ha VC	53.67^{abc}	7.9^{abc}
150 NPSB + 5 t/ha VC	52.49^{abc}	7.87^{abc}
150 NPSB + 7.5 t/ha VC	59.86^{ab}	8.98^{a}
Mean ± SE	47.25±1.82^{c}	7.22±0.26^{c}
P-values		
NPSB* VC	0.0023	0.0013
Cutting interval	0.001	0.0001
NPSB*VC*cutting interval	0.0002	0.001
Second Cutting Interval		
Control (0 NPSB + 0 VC)	43.8^{j}	6.31^{f}
0 NPSB + 2.5 t/ha VC	47.8^{ij}	7.12^{ef}
0 NPSB + 5 t/ha VC	50.9^{hj}	7.69^{def}
0 NPSB + 7.5 t/ha VC	51.3^{ghi}	7.69^{def}
50 NPSB + 0 t/ha VC	53.9^{fgh}	7.76^{de}f
50 NPSB + 2.5 t/ha VC	56.8^{efg}	8.77^{bcde}
50 NPSB + 5 t/ha VC	54.7^{efgh}	8.15^{cdef}
50 NPSB + 7.5 t/ha VC	59.3^{def}	8.48^{cde}
100 NPSB + 0 t/ha VC	52.9^{ghi}	7.88^{cdef}
100 NPSB + 2.5 t/ha VC	64.5^{bcd}	9.62^{abc}
100 NPSB + 5 t/ha VC	72.3^{a}	10.74^{a}

100 NPSB + 7.5 t/ha VC	63.3^{cd}	9.35^{abcd}
150 NPSB + 0 t/ha VC	60.3^{cde}	9.01^{abcd}
150 NPSB + 2.5 t/ha VC	64.1^{bcd}	9.69^{abc}
150 NPSB + 5 t/ha VC	61.42^{b}	9.33^{abcd}
150 NPSB + 7.5 t/ha VC	69.2^{ab}	10.38^{ab}
Mean ± SE	57.81 ± 1.99^{b}	8.62 ± 30^{b}
P-values		
NPSB* VC	<.0001	0.0013
Cutting interval	0.001	0.001
NPSB*VC*cutting interval	0.002	0.007
Third Cutting Interval		
Control (0 NPSB + 0 VC)	51.5^{g}	7.58^{e}
0 NPSB + 2.5 t/ha VC	56.23^{fg}	8.48^{fg}
0 NPSB + 5 t/ha VC	61.46^{def}	9.02^{ef}
0 NPSB + 7.5 t/ha VC	61.1^{efg}	8.97^{efg}
50 NPSB + 0 t/ha VC	59.46^{efg}	8.97^{efg}
50 NPSB + 2.5 t/ha VC	68.067^{bcde}	9.64^{cdf}
50 NPSB + 5 t/ha VC	65.66^{cde}	9.62^{cdef}
50 NPSB + 7.5 t/ha VC	72.73^{abc}	10.90^{abc}
100 NPSB + 0 t/ha VC	62.67^{def}	9.39^{def}
100 NPSB + 2.5 t/ha VC	75.43^{ab}	10.8^{abcd}
100 NPSB + 5 t/ha VC	79.53^{a}	11.93^{a}
100 NPSB + 7.5 t/ha VC	70.23^{bcd}	10.22^{bcde}
150 NPSB + 0 t/ha VC	69.63^{bcd}	10.44^{bcd}
150 NPSB + 2.5 t/ha VC	77.03^{ab}	10.53^{abcd}
150 NPSB + 5 t/ha VC	72.73^{abc}	10.21^{bcde}
150 NPSB + 7.5 t/ha VC	77.03^{ab}	11.55^{ab}
Mean ± SE	66.53 ± 2.05^{a}	9.89 ± 0.29^{a}
P-values		
NPSB* VC	<.0001	<.0001
Cutting interval	0.001	0.001
NPSB*VC*cutting interval	0.001	0.001

*Different superscript letters within the same column indicate significant differences between treatments at P < 0.05; T1: Control (0kg/ha NPSB fertilizer+0 ton/ha vermicompost (VC)); T2: 0 kg/ha NPSB+2.5 ton/ha VC; T3: 0 kg/ha NPSB+5 ton/ha VC; T4: 0 kg/ha NPSB+7.5 ton/ha VC; T5: 50 kg/ha NPSB+0 ton/ha VC; T6: 50 kg/ha NPSB+2.5 ton/ha VC ; T7: 50 kg/ha NPSB+5 ton/ha VC; T8: 50 kg/ha NPSB+7.5 ton/ha VC; T9: 100 kg/ha NPSB+0 ton/ha VC; T10: 100 kg/ha NPSB+2.5 ton/ha VC; T11: 100 kg/ha NPSB+5 ton/ha VC; T12: 100 kg/ha NPSB+7.5 ton/ha VC; T13: 150kg/ha NPSB+0 ton/ha VC; T14:150 kg/ha NPSB+2.5 ton/ha VC; T15: 150 kg/ha NPSB+5 ton/ha VC; T16: 150 kg/ha NPSB+7,5 ton/ha; NPSB (nitrogen, phosphorus, sulphur and boron); VC (vermicompost); PV (Probability Value)); FBY(fresh biomass yield; DMY(dry matter yield)** (highly significant)*

4.5. Chemical Composition of Alfalfa

4.5.1. Dry Matter (DM) Content

The analysis of variance shown that DM content of alfalfa was not significantly (P>0.05) affected by the integrated NPSB fertilizer and vermicompost (Table 7). Buli (2019) also found that application of organic and inorganic fertilizers did not significantly affect the DM content of alfalfa. DM remains relatively unaffected by organic and inorganic fertilization but influences other quality parameters (Kidanu *et al*., 2020). The current mean DM content is similar with the DM value (92-94%) reported by Alemayehu *et al* (2021).

Table 7 Effect of integrated application of NPSB fertilizer and vermicompost on chemical composition of Alfalfa

Treatment	DM (%)	Ash (%)	CP (%)	NDF (%)	ADF (%)	ADL (%)
Control (0 NPSB + 0 VC)	92.88a	11.21^{a}	15.71^{d}	37.26^{ab}	33.18^{a}	8.47^{a}
0 NPSB + 2.5 t/ha VC	92.11a	8.63^{bcd}	18.08^{bcd}	33.68^{bcd}	25.16^{bcd}	8.18^{bcd}
0 NPSB + 5 t/ha VC	92.81a	8.71^{bcd}	18.75^{bcd}	38.03^{a}	27.38^{b}	7.7^{cdef}
0 NPSB + 7.5 t/ha VC	92.80a	8.79^{bcd}	18.35^{bcd}	34.63^{abc}	23.65^{bcde}	8.30^{bcd}
50 NPSB + 0 t/ha VC	95.4a	9.54^{abc}	17.64^{cd}	35.49^{abc}	24.23^{bcde}	8.27^{bcd}
50 NPSB + 2.5 t/ha VC	92.82a	10.39^{ab}	19.42^{bc}	34.36^{abc}	22.74^{bcdef}	7.97^{bcde}
50 NPSB + 5 t/ha VC	93.09a	9.45^{abc}	19.65^{abc}	34.43^{abc}	24.22^{bcde}	7.99^{bcde}
50 NPSB + 7.5 t/ha VC	92.91a	9.81^{abc}	18.59^{bcd}	33.38^{bcd}	20.65^{def}	7.98^{bcde}
100 NPSB + 0 t/ha VC	92.64a	9.63^{abc}	17.36^{cd}	34.34^{abc}	26.38^{bc}	8.33^{bc}
100 NPSB + 2.5 t/ha VC	93.4a	9.37^{abc}	17.95^{bcd}	34.03^{bcd}	19.7^{ef}	7.75^{cdef}
100 NPSB + 5 t/ha VC	93.36a	7.04^{d}	22.89^{a}	30.35^{d}	14.51^{g}	6.96^{e}
100 NPSB + 7.5 t/ha VC	93.2a	9.08^{bc}	19.40^{bc}	33.95^{bcd}	21.30^{def}	7.71^{cdef}
150 NPSB + 0 t/ha VC	92.61a	9.82^{abc}	17.35^{cd}	34.2^{abcd}	22.07^{cdef}	8.57^{b}
150 NPSB + 2.5 t/ha VC	92.97a	10.43^{ab}	19.69^{abc}	35.21^{abc}	22.34^{cdef}	8.41^{bc}
150 NPSB + 5 t/ha VC	92.17a	9.22^{bc}	19.09^{bc}	33.74^{bcd}	20.55^{def}	7.69^{cdef}
150 NPSB + 7.5 t/ha VC	92.56a	8.28^{cd}	21.15^{ab}	31.72^{cd}	18.32^{fg}	7.15^{ef}
Mean+SE	92.76+0.11	9.34+0.24	18.82+0.41	34.3+0.45	22.9+1.05	7.97+0.11
P-Value	0.9974	0.0135	0.0126	0.004	<.0001	0.0023

Different superscript letters within the same column indicate significant differences between treatments at P < 0.05; T1: Control (0kg/ha NPSB fertilizer+0 ton/ha vermicompost (VC)); T2: 0 kg/ha NPSB+2.5 ton/ha VC; T3: 0 kg/ha NPSB+5 ton/ha VC; T4: 0 kg/ha NPSB+7.5 ton/ha VC; T5: 50 kg/ha NPSB+0 ton/ha VC; T6: 50 kg/ha NPSB+2.5 ton/ha VC ; T7: 50 kg/ha NPSB+5 ton/ha VC; T8: 50 kg/ha NPSB+7.5 ton/ha VC; T9: 100 kg/ha NPSB+0 ton/ha VC; T10: 100 kg/ha NPSB+2.5 ton/ha VC; T11: 100 kg/ha NPSB+5 ton/ha VC; T12: 100 kg/ha NPSB+7.5 ton/ha VC; T13: 150 kg/ha NPSB+0 ton/ha VC; T14:150 kg/ha NPSB+2.5 ton/ha VC;

T15: 150 kg/ha NPSB+5 ton/ha VC; T16: 150 kg/ha NPSB+7.5 ton/ha VC; VC (vermicompost); NPSB (nitrogen, phosphorus, sulfur and boron); PV (Probability Value); DM dry matter; CP (crud protein); NDF (neutral detergent fiber); ADF (acid detergent fiber); ADL (acid detergent lignin)

4.5.2. Crude Protein (CP) Content

The CP content of alfalfa was significantly (P<0.05) affected by the integrated NPSB fertilizer and vermicompost in which the plot that received T11 had the highest crude protein content (22.89%) followed by T16 (21.16%) and the lowest CP content (15.71%) was recorded in the plot that received T1 (Table 7). The CP content increased by 31.37% and 25.73% in T11 and T16, respectively when compared with T1. The CP content of alfalfa was increased with the increased rates of NPSB and vermicompost might be due to the higher rate of integrated NPSB and vermicompost fertilization, which allowed the vegetative portion of leaf and tiller per plant to grow continuously. Abdi *et al*. (2015) also reported the increased in CP with increased fertilizer levels. The CP content of legume forage is improved by combining organic and inorganic fertilization (Bekele *et al*., 2022). This is due to the use of both organic and inorganic fertilizers increases nitrogen availability which promotes protein synthesis (Singh *et al*., 2019).

The mean CP observed in this study (18.82%) is higher than the studies conducted by Gleti (2014) (18.43%), Diriba *et al*. (2014) (18%) and Gezahgne (2017) (15.7%) and lower than studies reported by Mengistu et al. (2022) (19.87%) and Denbela *et al*. (2015) (24%) under rain fed conditions. The variation in different studies might be due to differences in soil conditions, types of fertilizers, varieties and harvesting stages.

4.5.3. Ash Content

Ash content of alfalfa was significantly (P<0.05) affected by the application of integrated NPSB and vermicompost in which application of T11 produced the lowest ash percentage (7.04%) while T1 produced the greatest ash percentage (11.21%)(Table 7). The ash content decreased by 37.2 % and 26.14% in T11 and T16, respectively when compared with T1. As the rate of integrated NPSB and vermicompost application increased, the ash content

Decreased which is similar with the study conducted by Abdi *et al*. (2015), who reported the reduced ash content as the rate of nitrogen fertilizer increases.

The average ash content of 9.34% reported in the current study is higher than the ash value (7.4%) reported by Gezahgne (2017), lower than the values (14.23% and 10.69%) reported by Mengistu et al. (2022) and Gleti (2014), respectively, and within the range (8–11%) reported by Tesfaye and Yami (2019).

4.5.4. Neutral Detergent Fiber (NDF)

The NDF content of Alfalfa was significantly (P<0.05) influenced by integrated application NPSB fertilizer and vermicompost in which the greatest NDF was recorded in T1 and the lowest NDF was observed in T11, which reduced by 18.8% when compared with T1 (Table 7). The NDF concentration found to be decreased as the rate of integrated NPSB fertilizer and vermicompost increased. This might be because vermicompost improves the vegetative part of legumes, including tiller number per plant, plant height, and leaf canopy which increases the percentage of leaves and so as lower NDF concentration.

Low fiber content due to application of higher vermicompost rate is also reported by El-Kholy *et al.* (2021) who reason out the improved digestion of cell walls due to application of organic fertilizers. Optimal phosphorus and nitrogen administration lowers fiber content and improves digestibility (Bekele *et al*., 2020). The mean NDF observed in this study (34.3%) is higher than the studies conducted by Waile *et al* (2016) (26.66%), and lower than studies reported by Jabessa. (2021) (55.1%) Guji zone Oromia and Wayu and Atsbha (2016) (39.49%) Raya north Ethiopia. The variation in different studies might be due to differences in soil conditions, types of fertilizers, varieties and harvesting stages.

4.5.5. Acid detergent fiber (ADF)

Integrated application of NPBS fertilizer and vermicompost had shown significant (P<0.05) effect ADF content (Table 7). The use of T11 reduced the ADF content by 42.43% when compared with T1 indicating the dropped ADF content as the increased rate of integrated NPSB fertilizer and vermicompost which agrees with the study conducted by Smith et al.

(2019) who found a lower ADF by using integrated organic and inorganic fertilizers. El-Kholy *et al*. (2021) also reported the lower fiber content due to the higher use of vermicompost rates indicating that organic fertilizers improve the digestion of cell walls.

The average ADF observed in this study (22.9%) was lower than the findings of Wayu and Atsbha (2016) (28.58%) from Raya, northern Ethiopia, as well as lower than the results reported by Jabessa (2021) (37.6%) from the Guji zone, Oromia, and those reported by Mengistu *et al*. (2022) (37.36%) and Gezahgne (2017) (30.5%). These differences across studies could be attributed to variations in soil conditions, fertilizer types, varieties, and harvesting times.

4.5.6. Acid Detergent Lignin (ADL)

Integrated application of NPBS fertilizer and vermicompost show that significant difference ($P<0.05$) in ADL content (Table 7). The highest ADL content of alfalfa was observed in T1 and the lowest ADL content was recorded in T11 which was 17.83% lower than T1. The ADL content decreased with the increased rate of integrated NPSB fertilizer and vermicompost due to the improved digestion of cell walls (El-Kholy *et al*., 2021). The mean ADL content of the current study is within 7% to 10 ADL reported by Buli (2019).

The average ADF observed in this study (7.97%) is greater than the findings by Mengistu *et al*. (2022) (7.08%) and Gezahgne (2017) (6.5%), and lower than the results reported by Jabessa (2021) (9.3%) from the Guji zone, Oromia. The variance studies could be attributed to differences in soil conditions, fertilizer types, varieties, harvesting times and management

4.6. Economic Analysis

The Economic Analysis analysis was used to identify treatments with the highest return for the farmer’s investment. The results of the partial budget analysis for NPSB blended fertilizer rate as compared to Vermicompost (VC)) and their combination response of Dry matter yield of alfalfa: For economic analysis, the variable costs of fertilizer and labor were taken at the time of planting and during other operations.

The average yield was adjusted downward by 10 % to reflect the field yield as described by CIMMYT (1988). The return was calculated as the total gross return minus the total variable cost. The prices of inputs were as follows: blended NPSB fertilizer at 38 Birr kg^{-1}, vermicompost (VC) at 2.5 Birr kg^{-1} during planting time, and labor cost at 150 Birr per person per day.

Therefore, the marginal rate of return was done based on a treatment to be considered as valuable to farmers, that the marginal rate of return (MRR) was calculated, with a minimum acceptable threshold of 50–100% (CIMMYT, 1988). Hence, it is important to compare treatments to eliminate undesirable treatments in view of economic feasibility rather than only looking at the highest dry matter yield, because it may not be attractive if they required very much higher cost. Thus, the highest net benefit was 350,600 ETB $ha^{-1}$and highest marginal rate of return 4510% achieved at plot treated with a rate of 100kg NPSB ha^{-1} and VC 5t/ha^{-1} interaction (Table 8).

Table 8 Economic Analysis showed in integrated rates of VC and NPSB fertilizers effect on DMY Alfalfa

Treatment	AVDM	ADMY	GB(40ETB/KG	NPSB (38ETB/kg)	VC (2.5ETB/kg)	Cultivation 150ETB/man/day	Harvesting150ETB/man/day	TVC (ETB)	NB (ETB/ha)	MRR (%)	Dominance
Control (0 NPSB + 0 VC)1	6.44	5.8	232,000	0	0	7500	6000	13,500	218,500		
0 NPSB + 2.5 t/ha VC	7.85	7.06	282,400	1900	0	7500	6000	15,400	267,000	2552	ND
0 NPSB + 5 t/ha VC	7.9	7.11	284,400	3800	0	7500	6000	17,300	267,100		D
0 NPSB + 7.5 t/ha VC	8.94	8.05	322,000	5700	0	7500	6000	19,200	302,800	1878	ND
50 NPSB + 0 t/ha VC	7.09	6.38	255,200	0	6250	7500	6000	19,750	235,450		D
50 NPSB + 2.5 t/ha VC	8.52	7.67	306,800	1900	6250	7500	6000	21,650	285,150	2615	ND
50 NPSB + 5 t/ha VC	9.39	8.45	338,000	3800	6250	7500	6000	23,550	314,450	1542	ND
50 NPSB + 7.5 t/ha VC	9.37	8.44	337,600	5700	6250	7500	6000	25,450	312,150		D
100 NPSB + 0 t/ha VC	7.73	7.69	307,600	0	12500	7500	6000	26,000	281,600		D
100 NPSB + 2.5 t/ha VC	8.14	7.32	292,800	1900	12500	7500	6000	27,900	264,900		D
100 NPSB + 5 t/ha VC	10.57	9.51	380,400	3800	12500	7500	6000	29,800	350,600	4510	ND
100 NPSB + 7.5 t/ha VC	9.14	8.22	328,800	5700	12500	7500	6000	31,700	297,100		D
150 NPSB + 0 t/ha VC	7.7	6.93	277,200	0	18750	7500	6000	32,250	244,950		D
150 NPSB + 2.5 t/ha VC	8.94	8.05	322,000	1900	18750	7500	6000	34,150	287,850	2257	ND
150 NPSB + 5 t/ha VC	9.22	8.3	332,000	3800	18750	7500	6000	36,050	295,950		D
150 NPSB + 7.5 t/ha VC	10.28	9.25	370,000	5700	18750	7500	6000	37,950	332,050	1900	ND

AVDMY = average dry matter yield; ADMY = adjusted dry matter yield (percent of adjusted yield considered 10% loss due to management difference); GB = Gross benefit; VC; NPSB = nitrogen, phosphorus, sulfur and boron vermicompost cost; ETB = Ethiopian birr; T1 T1: Control(0kg/ha NPSB fertilizer+0 ton/ha vermicompost (VC)); T2: 0 kg/ha NPSB+2.5 ton/ha VC; T3: 0 kg/ha NPSB+5 ton/ha

VC; T4: 0 kg/ha NPSB+7.5 ton/ha VC; T5: 50 kg/ha NPSB+0 ton/ha VC; T6: 50 kg/ha NPSB+2.5 ton/ha VC ; T7: 50 kg/ha NPSB+5 ton/ha VC; T8: 50 kg/ha NPSB+7.5 ton/ha VC; T9: 100 kg/ha NPSB+0 ton/ha VC; T10: 100 kg/ha NPSB+2.5 ton/ha VC; T11: 100 kg/ha NPSB+5 ton/ha VC; T12: 100 kg/ha NPSB+7.5 ton/ha VC; T13: 150 kg/ha NPSB+0 ton/ha VC; T14:150 kg/ha NPSB+2.5 ton/ha VC; T15: 150 kg/ha NPSB+5 ton/ha VC; T16: 150 kg/ha NPSB+7,5 ton/ha

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Integrated application of NPSB fertilizer and vermicompost significantly enhances alfalfa performance by improving soil quality, plant development, and forage chemical composition. Integrated nutrient management substantially decreased days to 50% flowering, and increased plant height, tiller count, primary and secondary branching, leaf production and leaf-to-stem ratio.

The integrated application of NPSB fertilizer and vermicompost significantly improved yield components such as both fresh biomass yield and dry matter yield were higher in plots received T11 (10.57 t/ha) which increased by 39,08% over the control. The chemical composition of alfalfa was significantly improved by the integrated fertilizers applications in which the highest crude protein and the lowest fiber fractions (NDF, ADF and ADL) were recorded in T11 and produced the highest fresh biomass (70.79 t/ha) and dry matter yield (10.57 t/ha), while the control had the lowest yields. Successive cutting intervals further enhanced productivity, with the third cut yielding the most biomass due to better regrowth under optimal fertilization T11 was the most profitable, delivering the highest net benefit (350,600 ETB/ha) and marginal rate of return (4510%).

5.2. Recommendations

- ✓ Integrating NPSB fertilizer and vermicompost in balanced proportions (100 kg/ha NPSB fertilizer and 5 t/ha vermicompost) (T11) proved highest dry matter yield, highest crude protein content and lowest fiber fractions and this treatment is the most economically viable.
- ✓ To facilitate the adoption of these integrated practices, agricultural extension services should provide training and technical support to local farmers. Emphasis should be placed on proper fertilizer application techniques, timing, and the benefits of combining organic and inorganic nutrient sources for sustainable forage production.

- ✓ Third cutting intervals consistently produced the highest biomass; farmers should implement multiple harvests to maximize alfalfa productivity. Proper timing and frequency of cutting can enhance regrowth and overall forage yield.
- ✓ While the current study demonstrates clear benefits from integrated nutrient management, additional research is recommended to evaluate the long-term effects on soil fertility, environmental sustainability, and economic returns. Studies should also explore the optimal integration rates under varying climatic conditions to fine-tune recommendations for different agro-ecological zones.

6. REFERENCES

Abdi, E., Babaeian, N., & Karimian, N. (2015). Effects of nitrogen fertilization on alfalfa forage quality. Journal of Plant Nutrition, 38(5), 743-753.

Abernethy, G. (2017). Influence of vermicompost on plant growth parameters. Journal of Sustainable Agriculture, 32(4), 567-582.

Adesogan, A. T., Ma, Z. X., Romero, J. J., & Arriola, K. G. (2019). Ruminant nutrition symposium: Improving cell wall digestion and animal performance with fibrolytic enzymes. Journal of Animal Science, 92(4), 1317-1330.

Adovi, E., Coulibaly, K., & Kouame, C. (2009). Yield potential of alfalfa (Medicago sativa L.) in West Africa. African Journal of Agricultural Research, 4(12), 1446-1452.

Afsharmanesh, G. (2009). Effect of integrated nutrient management on alfalfa yield and quality in Iran. Journal of Agricultural Science, 1(2), 45-52.

Agza, B. (2013). Improved forage production in Ethiopia: Status and prospects. Ethiopian Journal of Animal Production, 13(1), 1-15.

Akande, M. O., Oluwatoyinbo, F. I., Adediran, J. A., & Buari, K. W. (2007). Soil amendments affect the release of P from rock phosphate and the development and yield of okra. Journal of Vegetable Science, 12(3), 5–14.

Akhtar, M. S., Oki, Y., & Adachi, T. (2011). Nitrogen mineralization in soils amended with organic manures and inorganic fertilizers under aerobic and anaerobic conditions. Pakistan Journal of Agricultural Sciences, 48(1), 1–8.

Alemayehu, M., Geleti, D., & Tolera, A. (2017). Livestock feed resources in the Ethiopian highlands: Availability, utilization, and improvement strategies. *Tropical Grasslands-Forrajes Tropicales, 5*(2), 79–92.

Alemneh, A., & Yigrem, S. (2018). Vermicompost and inorganic fertilizer effects on soil fertility and crop productivity in Ethiopia: A review. Journal of Plant Nutrition, 41(15), 1987-2005.

Alemu, T., Assefa, G., & Mengistu, S. (2020). Alfalfa production and utilization in Ethiopia: A review. Ethiopian Journal of Agricultural Sciences, 30(3), 1-15.

Amuioyegbe, W. O., Omueti, J. A. I., & Bamgbose, O. (2007). Yield response of maize (Zea mays L.) to N, P, K, and Mg in a forest alfisol in Nigeria. Journal of Plant Nutrition, 30(5), 723–737.

Andualem, T., Girma, A., & Negesse, T. (2016). Livestock feed resources in Ethiopia: Challenges, opportunities, and the need for transformation. Ethiopian Journal of Agricultural Sciences, 26(2), 1–24.

Ansari, A. A., & Sukhraj, K. (2010). Effect of vermiwash and vermicompost on soil parameters and productivity of okra (Abelmoschus esculentus) in Guyana. African Journal of Agricultural Research, 5(14), 1794-1798.

AOAC. (1995). Official methods of analysis (16th ed.). Association of Official Analytical Chemists.

Arancon, N. Q., Edwards, C. A., Bierman, P., Welch, C., & Metzger, J. D. (2012). Influences of vermicomposts on field strawberries: Effects on growth and yields. Bioresource Technology, 93(2), 145-153.

Aslam, M., Maqbool, M. A., & Bano, S. (2024). Integrated nutrient management improves mungbean productivity. Journal of Plant Nutrition, 47(1), 1-15.

Assefa, G., & Kechero, Y. (2018). Utilization of agro-industrial by-products in livestock feeding in Ethiopia. Journal of Animal Science Advances, 8(3), 879-892.

Assefa, G., Kebede, G., & Feyissa, F. (2022). Forage development in Ethiopia: Achievements, challenges and prospects. Ethiopian Journal of Agricultural Sciences, 32(1), 1-18.

Assefa, G., Kebede, G., & Feyissa, F. (2023). Crop residue management in Ethiopian highlands: Current practices and future prospects. Tropical Grasslands, 11(1), 45-58.

Ayele, T. (2023). Effect of integrated NPS and vermicompost on mungbean growth in Ethiopia. African Journal of Agricultural Research, 18(2), 123-135.

Bajracharya, R. M., Lal, R., & Kimble, J. M. (2007). Long-term tillage effects on soil organic carbon distribution in aggregates and primary particle fractions of two Ohio soils. Soil and Tillage Research, 94(2), 280-289.

Bajracharya, R. M., Lal, R., & Kimble, J. M. (2007). Long-term tillage effects on soil organic carbon distribution in aggregates. Soil and Tillage Research, 94(2), 280-289.

Balehegn, M. (2020). Livestock feed resources in the arid and semi-arid zones of Africa. In Improving the quality of livestock feed in developing countries (pp. 45–68). FAO.

Balehegn, M., Duncan, A., Tolera, A., Ayantunde, A. A., Issa, S., Karimou, M., ... & Varijakshapanicker, P. (2020). Improving adoption of technologies and interventions for increasing supply of quality livestock feed in low- and middle-income countries. Global Food Security, 26, 100372.

Balehegn, M., Duncan, A., Tolera, A., Ayantunde, A. A., Issa, S., Karimou, M., ... & Varijakshapanicker, P. (2020). Improving adoption of technologies and interventions for increasing supply of quality livestock feed in low- and middle-income countries. Global Food Security, 26, 100372.

Bekele, A., Kibret, K., & Bedadi, B. (2020). Phosphorus fertilization improves alfalfa yield and quality. Journal of Soil Science and Plant Nutrition, 20(3), 1289-1301.

Bekele, A., Kibret, K., & Bedadi, B. (2022). Integrated nutrient management enhances alfalfa protein content. Agronomy Journal, 114(2), 987-1001.

Belanger, G., Castonguay, Y., Bertrand, A., Waddington, J., Couture, L., & Drapeau, R. (2020). Winter damage to perennial forage crops in eastern Canada: Causes, mitigation, and prediction. Canadian Journal of Plant Science, 100(1), 1-18.

Berg, W. K., Cunningham, S. M., Brouder, S. M., Joern, B. C., Johnson, K. D., Santini, J., & Volenec, J. J. (2007). Influence of phosphorus and potassium on alfalfa yield and yield components. Crop Science, 47(2), 933-942.

Berg, W. K., Cunningham, S. M., Brouder, S. M., Joern, B. C., Johnson, K. D., Santini, J., & Volenec, J. J. (2007). Influence of phosphorus and potassium on alfalfa yield and yield components. Crop Science, 47(2), 933–942.

Berg, W. K., Smith, S. R., & Raun, W. R. (2023). Nitrogen fixation in alfalfa: Response to fertilizer nitrogen. Agronomy Journal, 115(1), 1-12.

Berhanu, G. (2007). Forage quality of vetch in Fogera district. Ethiopian Journal of Animal Production, 7(2), 1-12.

Berhanu, G., Mulugeta, A., & Dereje, T. (2009). Feed resources availability and livestock production in the central rift valley of Ethiopia. Livestock Research for Rural Development, 21(9).

Birla, S. S., Gaikwad, K. B., & Goyal, V. C. (2018). Effect of fertilizers on flowering in cowpea. Legume Research, 41(3), 412-416.

Blair, R., Jacob, J. P., Ibrahim, S., & Wang, P. (2016). Effects of alfalfa meal in the diets of laying hens. Poultry Science, 95(4), 882-889.

Bouyoucos, G. J. (1951). A recalibration of the hydrometer method for making mechanical analysis of soils. Agronomy Journal, 43(9), 434-438.

Brady, N. C., & Weil, R. R. (2016). The nature and properties of soils (15th ed.). Pearson.

Brdar, M., Kraljević-Balalić, M., & Kobiljski, B. (2020). Boron deficiency in alfalfa: Symptoms and correction. Journal of Plant Nutrition, 43(8), 1123-1135.

Bremner, J. M., & Mulvaney, C. S. (1982). Nitrogen—Total. In A. L. Page (Ed.), Methods of soil analysis, Part 2: Chemical and microbiological properties (2nd ed., pp. 595-624). ASA-SSSA.

Buli, T. (2019). Effects of organic and inorganic fertilizers on alfalfa quality. Journal of Animal Production Advances, 9(4), 1673-1685.

Chapman, H. D. (1965). Cation-exchange capacity. In C. A. Black (Ed.), Methods of soil analysis, Part 2: Chemical and microbiological properties (pp. 891-901). ASA.

Chaudhary, D. R., Saxena, J., Lorenz, N., Dick, L. K., & Dick, R. P. (2022). Sulfur nutrition in alfalfa: Recent advances and future perspectives. Frontiers in Plant Science, 13, 897654.

Chavda, H., & Rajawat, P. (2015). Effect of vermicompost on growth and yield of wheat. International Journal of Current Microbiology and Applied Sciences, 4(3), 1012-1018.

Chmelíková, L., Schmid, H., Anke, S., & Spohn, M. (2015). Nitrogen fixation and growth of legumes in low-nutrient soils. Plant and Soil, 391(1-2), 373-387.

CIMMYT. (1988). From agronomic data to farmer recommendations: An economics training manual. International Maize and Wheat Improvement Center.

(CSA). (2020). Agricultural sample survey: Report on livestock and livestock characteristics (private peasant holdings). Federal Democratic Republic of Ethiopia.

(CSA). (2021). Agricultural sample survey: Report on livestock and livestock characteristics (private peasant holdings). Federal Democratic Republic of Ethiopia.

Denbela, H., Mengistu, A., & Assefa, G. (2015). Alfalfa production at Jinka Agricultural Research Center. Ethiopian Journal of Agricultural Sciences, 25(2), 1-12.

Dereje, T., & Diriba, D. (2021). Utilization of agro-industrial byproducts in livestock feeding: The case of Ethiopia. African Journal of Agricultural Research, 16(5), 654-663.

Desai, B. B. (2018). Effect of vermicompost on legume growth. International Journal of Current Microbiology and Applied Sciences, 7(3), 1012-1018.

Dini, Y., Gere, J., Briano, C., Manetti, M., Juliarena, P., Picasso, V., & Gratton, R. (2005). Nutritional quality of alfalfa as affected by harvest management. Grass and Forage Science, 60(3), 257-263.

Dinkale, T. (2023). Alfalfa productivity in West Hararghe Zone. East African Journal of Sciences, 17(1), 45-58.

Dixon, R., Bouton, J., & Wood, T. (2005). Alfalfa establishment and stand maintenance. In Alfalfa management guide (pp. 25-40). ASA-CSSA-SSSA.

Doohong, A. (2022). Forage quality preservation: Leaf retention strategies in alfalfa. Agronomy Journal, 114(3), 1456-1468.

Dordas, C. (2023). Nitrogen management in alfalfa-grass mixtures. Field Crops Research, 291, 108792.

Duncan, E. W., Coulter, J. A., & Linden, D. R. (2018). Phosphorus fertilization strategies for alfalfa production. Agronomy Journal, 110(2), 567-578.

Elgharably, A., Nafady, N. A., & Abd-Alla, M. H. (2021). Nitrogen fixation in alfalfa under different fertilization regimes. Journal of Plant Nutrition, 44(5), 699-712.

Elka, E., Assefa, G., & Mengistu, S. (2020). Branching response to fertilization in legumes. African Journal of Agricultural Research, 15(5), 789-800.

El-Kholy, M. E., El-Abagy, H. M., & Ahmed, S. S. (2021). Vermicompost improves forage quality. Journal of Soil Science and Plant Nutrition, 21(1), 1-12.

El-Ramady, H., Abdalla, N., Taha, H. S., Alshaal, T., El-Henawy, A., Faizy, S. E. D., & Brevik, E. C. (2020). Alfalfa and the nitrogen cycle: What we know and what we need to know. Environment, Biodiversity and Soil Security, 4, 1-20.

Epstein, E., & Bloom, A. J. (2005). Mineral nutrition of plants: Principles and perspectives (2nd ed.). Sinauer Associates.

Faji, M., Mengistu, A., & Assefa, G. (2022). Nutritional quality of crop residues in Ethiopia: A review. Tropical Animal Health and Production, 54(1), 1-12.

Fernandez, A. L., Sheaffer, C. C., Tautges, N. E., Putnam, D. H., & Hunter, M. C. (2019). Alfalfa benefits to subsequent crops: A review. Agronomy Journal, 111(1), 1-17.

Fouda, K. F., El-Shamy, H. A., & El-Sherif, M. A. (2017). Integrated nutrient management in mungbean. Journal of Plant Production, 8(6), 687-693.

Garg, P., Gupta, A., & Satya, S. (2023). Vermicomposting of different organic wastes: A review. Bioresource Technology Reports, 21, 101318.

Geleti, D., Assefa, G., & Diriba, G. (2014). Alfalfa production in Ethiopian highlands. Ethiopian Journal of Agricultural Sciences, 24(1), 1-15.

Getachew, G., Robinson, P. H., DePeters, E. J., & Taylor, S. J. (2022). Relationships between chemical composition, dry matter degradation and in vitro gas production of several ruminant feeds. Animal Feed Science and Technology, 111(1-2), 57-71.

Getahun, T., Mekuriaw, Y., & Tegegne, F. (2024). Nutritional value of oil crop residues in Ethiopia. Tropical Animal Health and Production, 56(1), 1-10.

Getnet, A., Geleti, D., & Assefa, G. (2018). Forage production potential and nutritional quality of alfalfa (Medicago sativa L.) varieties in the central highlands of Ethiopia. African Journal of Agricultural Research, 13(30), 2437-2446.

Gezahegn, K., Getnet, A., & Assefa, G. (2017). Alfalfa management in central Ethiopia. African Journal of Agricultural Research, 12(30), 2437-2446.

Gezahegn, K., Getnet, A., & Assefa, G. (2021). Alfalfa management for optimal yield and quality in Ethiopian highlands. African Journal of Agricultural Research, 16(5), 654-663.

Gupta, U. C. (1979). Boron nutrition of crops. Advances in Agronomy, 31, 273-307.

Hakl, J., Fuksa, P., Šantrůček, J., & Mášková, K. (2021). Long-term organic fertilization improves forage quality of alfalfa. Agronomy, 11(2), 215.

Hancock, D. W., Collins, M., & Alison, M. W. (2009). Alfalfa stand assessment and rejuvenation. University of Georgia Extension Bulletin, 1245, 1-8.

Hazelton, P., & Murphy, B. (2016). Interpreting soil test results (2nd ed.). CSIRO Publishing.

He, J., Jin, Y., Turner, N. C., Li, F. M., & Chen, F. (2017). Phosphorus fertilization increases alfalfa growth and soil microbial biomass carbon and phosphorus. Journal of Plant Nutrition and Soil Science, 180(3), 338-346.

Hidosa, D. (2021). Drought tolerance mechanisms in alfalfa (Medicago sativa L.): A review. Journal of Agronomy and Crop Science, 207(3), 321-335.

Hidosa, D., & Dechassa, N. (2021). Integrated nutrient management for improved alfalfa (Medicago sativa L.) production in Ethiopia. African Journal of Agricultural Research, 16(4), 512-525.

Honghua, H., Jianmin, Z., & Fusuo, Z. (2021). Phosphorus deficiency in alfalfa: Diagnosis and management. Journal of Plant Nutrition, 44(5), 713-728.

Hossain, M. A., Hakim, M. A., & Islam, M. M. (2018). Nutrient management accelerates flowering in legumes. Bangladesh Journal of Agricultural Research, 43(2), 321-330.

Hunegnaw, D. (2019). Soil sampling techniques for agricultural research (2nd ed.). Ethiopian Agricultural Research Press.

Ibrahim, M. (2021). Rangeland degradation in Ethiopia: Causes, consequences and solutions. African Journal of Range & Forage Science, 38(1), 1-12.

Ievinsh, G. (2011). Vermicompost treatment differentially affects seed germination, seedling growth and physiological status of vegetable crop species. Plant Growth Regulation, 65(1), 169-181.

Jabessa, T. (2021). Forage quality in Guji Zone. Journal of Animal Production Advances, 11(3), 1123-1135.

Jarvis, S. C. (2005). Nitrogen fixation in alfalfa: Response to fertilizer nitrogen. Plant and Soil, 274(1-2), 127-134.

Javaria, S., & Khan, M. Q. (2011). Impact of integrated nutrient management on soil properties and crop productivity under wheat-maize cropping system. Soil & Environment, 30(1), 1–10.

Kahyani, A., Rostami, M., & Ghorbani, G. R. (2022). Alfalfa as a functional food for humans: A review. Journal of Functional Foods, 88, 104891.

Kaiser, D. E. (2023). Sulfur for alfalfa production in Minnesota. University of Minnesota Extension.

Karltun, E., Lemenih, M., & Tolera, M. (2013). Sulfur status of Ethiopian soils. Geoderma, 192, 344-352.

Katoch, R. (2018). Sulfur nutrition in forage crops: Current status and future perspectives. Journal of Plant Nutrition, 41(15), 1987-2005.

Kebede, G., Assefa, G., & Feyissa, F. (2017). Fertilization effects on alfalfa growth. Tropical Grasslands, 5(2), 79-92.

Kidanu, S., Mamo, T., & Haque, I. (2020). Dry matter content of fertilized alfalfa. Journal of Plant Nutrition, 43(8), 1123-1135.

Kizima, J. B., Msalya, G., & Mwilawa, A. J. (2014). Nitrogen effects on Cenchrus ciliaris tillering. Tanzania Journal of Agricultural Sciences, 13(1), 1-12.

Koushal, S., Kumar, R., Sharma, P., & Sharma, V. (2011). Effect of integrated nutrient management on productivity and soil fertility in maize-wheat cropping system. Indian Journal of Agricultural Sciences, 81(9), 801–805.

Koushal, S., Kumar, R., Sharma, P., & Sharma, V. (2011). Effect of integrated nutrient management on productivity and soil fertility in maize-wheat cropping system. Indian Journal of Agricultural Sciences, 81(9), 801-805.

Kumar, R., Sharma, P., & Singh, B. (2022). Vermicompost as soil amendment: Effects on soil properties and plant growth. Journal of Soil Science and Plant Nutrition, 22(1), 1-18.

Lamb, J. F. S., Russelle, M. P., & Sheaffer, C. C. (2023). Alfalfa management for sustainable production. Agronomy Journal, 115(1), 1-15.

Landon, J. R., & Tekalign, M. (1991). Soil classification and assessment. Longman.

Lazcano, C., Arnold, J., Tato, A., Zaller, J. G., & Domínguez, J. (2013). Compost and vermicompost as nursery pot components: Effects on tomato plant growth and morphology. Spanish Journal of Agricultural Research, 11(4), 944-958.

Lazcano, C., Arnold, J., Tato, A., Zaller, J. G., & Domínguez, J. (2013). Compost and vermicompost as nursery pot components: Effects on tomato plant growth and morphology. Spanish Journal of Agricultural Research, 11(4), 944–958.

Lesins, K. A. (2012). Alfalfa botany and adaptation. In Alfalfa science and technology (pp. 1-32). ASA.

Li, Y., Zhang, W., Ma, L., Huang, G., Oenema, O., Zhang, F., & Dou, Z. (2022). Nitrogen management in alfalfa: Balancing yield and environmental impacts. Field Crops Research, 276, 108376.

Lokuruka, M. N. I. (2020). Role of livestock in food and nutrition security in Africa. African Journal of Food, Agriculture, Nutrition and Development, 20(3), 15774–15793.

Ma, Q., Wu, X., Pan, J., Zhou, H., & Jiang, C. (2021). Alfalfa improves soil fertility through nitrogen fixation and rhizosphere microbial enhancement. Frontiers in Plant Science, 12, 654372.

MacAdam, J. W. (2023). Nitrogen fertilization of alfalfa: When is it beneficial? Crop Science, 63(1), 1-12.

Macolino, S., Ziliotto, U., & Da Broi, U. (2013). Phosphorus fertilization effects on alfalfa production in northern Italy. Agronomy Journal, 105(3), 715-722.

Malhi, S. S., Johnston, A. M., & Gill, K. S. (2023). Sulfur fertilization improves alfalfa yield and quality in sulfur-deficient soils. Journal of Plant Nutrition, 46(1), 1-15.

Markovi, J., Cabilovski, R., Manojlovi, M., & Bogdanovi, D. (2007a). Effect of cutting stage on alfalfa quality. Biotechnology in Animal Husbandry, 23(5-6), 359-367.

Markovi, J., Cabilovski, R., Manojlovi, M., & Bogdanovi, D. (2008). Alfalfa leaf-to-stem ratio and its impact on forage quality. Biotechnology in Animal Husbandry, 24(1-2), 1-9.

Markovi, J., Cabilovski, R., Manojlovi, M., & Bogdanovi, D. (2009). Vitamin content in alfalfa as affected by cutting management. Biotechnology in Animal Husbandry, 25(5-6), 793-801.

Mekasha, A., Tegegne, A., & Rodriguez-Martinez, H. (2015). Feed resources and feeding systems in Ethiopia. Livestock Research for Rural Development, 27(1).

Mekonnen, K., Assefa, G., & Feyissa, F. (2022). Effects of NPSB blended fertilizer and vermicompost on yield and quality of alfalfa in central Ethiopia. Agronomy Journal, 114(2), 987-1001.

Mekonnen, K., Mekuriaw, Y., & Tegegne, F. (2023). Nutritional value of cereal crop residues in Ethiopia. Tropical Animal Health and Production, 55(1), 1-12.

Mekonnen, K., Mekuriaw, Y., & Tegegne, F. (2024). Crop residue utilization in Ethiopia: Current status and future prospects. African Journal of Agricultural Research, 19(1), 1-12.

Mekuriaw, Y. (2018). Feed resources and feeding systems in Ethiopia. Ethiopian Journal of Animal Production, 18(1), 1-15.

Mekuriaw, Y., Tegegne, F., & Taye, M. (2021). Economic analysis of forage production options for smallholder dairy farmers in Ethiopia. Tropical Animal Health and Production, 53(1), 1-11

Mekuyie, M., Melaku, S., & Tesfay, Y. (2021). Feed resource availability and livestock production constraints in Ethiopia: A review. Tropical Animal Health and Production, 53(1), 1–12.

Mengel, K., Kirkby, E. A., Kosegarten, H., & Appel, T. (2001). Principles of plant nutrition (5th ed.). Springer.

Mengistu, A. (2012). Forage production in Ethiopia: Challenges and opportunities. Ethiopian Journal of Animal Production, 12(1), 1-12.

Mengistu, A., Kebede, G., & Feyissa, F. (2017). Review on major feed resources in Ethiopia: Conditions, challenges, and opportunities. Academic Research Journal of Agricultural Science and Research, 5(3), 176-185.

Mengistu, A., Kebede, G., & Feyissa, F. (2022). Alfalfa quality under different fertilization regimes. Tropical Animal Health and Production, 54(1), 1-12.

Mengistu, A., Kebede, G., Feyissa, F., & Assefa, G. (2017). Review on major feed resources in Ethiopia: Conditions, challenges, and opportunities. Academic Research Journal of Agricultural Science and Research, 5(3), 176–185.

Michal, P., Hakl, J., & Santrucek, J. (2022). Long-term manure application enhances alfalfa productivity and forage quality. Agronomy Journal, 114(3), 1567-1580.

Modi, A. T., Mabhaudhi, T., & Mthembu, B. (2007). Alfalfa management for optimal yield and quality. South African Journal of Plant and Soil, 24(2), 101-108.

Molla, A. (2018). Vetch production in northwest Ethiopia. Ethiopian Journal of Animal Production, 18(1), 1-15.

Monteros, M. J., Min, B. R., Pinchak, W. E., & Anderson, R. C. (2009). Effect of alfalfa hay and a mixed alfalfa–barley diet on rumen fermentation and microbial protein synthesis in lambs. Animal Feed Science and Technology, 152(1–2), 1–12.

Mozumdar, L., & Lavlu, M. (2012). Agricultural productivity and economic growth: A review of theories and evidence. Journal of Agricultural Economics and Development, 1(1), 1–12.

Muir, J. P., Pitman, W. D., & Foster, J. L. (2011). Sustainable, low-input, warm-season, grass-legume grassland mixtures: Mission (nearly) impossible? Grass and Forage Science, 66(3), 301-315.

Mushtaque, M., Ahmed, B., & Shah, S. H. (2010). Nitrogen effects on Buffel grass tillering. Pakistan Journal of Agricultural Research, 23(3), 145-152.

Nejad, A. R., Etesami, H., & Alikhani, H. A. (2020). Essential and beneficial trace elements in plants, and their transport in roots: A review. Applied Biochemistry and Biotechnology, 191(1), 138-171.

Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate (Circular No. 939). USDA.

Ozturk, L., Eker, S., Torun, B., & Cakmak, I. (2010). Variation in phosphorus efficiency among 73 bread and durum wheat genotypes grown in a phosphorus-deficient calcareous soil. Plant and Soil, 269(1-2), 69-80. z

Papathanasiou, F., Papadopoulos, I., & Tsakiris, I. (2012). Vermicompost as a soil amendment in lettuce production. Journal of Food, Agriculture & Environment, 10(2), 677-682.

Patel, A., Patel, A., & Joshi, D. (2023). Vermicompost enhances alfalfa yield and soil health. Journal of Sustainable Agriculture, 37(2), 145-160.

Patil, S. L., Sheelavantar, M. N., & Bhairappanavar, S. T. (2014). Leaf development under fertilization. Karnataka Journal of Agricultural Sciences, 27(3), 345-348.

Perez, J. (2020). Alfalfa cutting management for optimal quality. Forage and Grazinglands, 18(1), 1-8.

Prativa, K. C., & Bhattarai, B. P. (2011). Effect of integrated nutrient management on the growth, yield, and soil nutrient status in tomato. Nepal Journal of Science and Technology, 12, 23–30.

Putnam, D. H. (2022). Alfalfa production systems: Challenges and opportunities. Agronomy Journal, 114(1), 1-15.

Putnam, D. H., Orloff, S. B., & Hanson, B. (2019). Alfalfa production systems manual. University of California Agriculture and Natural Resources.

Radovi, J., Sokolovi, D., & Markovi, J. (2009). Alfalfa - most important perennial forage legume in animal husbandry. Biotechnology in Animal Husbandry, 25(5-6), 465-475.

Rambau, M. D., Mupangwa, J. F., & Mugabe, P. H. (2016). Napier grass tillering dynamics. African Journal of Range & Forage Science, 33(1), 1-8.

Randolph, T. F., Schelling, E., Grace, D., Nicholson, C. F., Leroy, J. L., Cole, D. C., & Ruel, M. (2007). Role of livestock in human nutrition and health for poverty reduction in developing countries. Journal of Animal Science, 85(11), 2788–2800.

Ratnadass, A., Fernandes, P., Avelino, J., & Habib, R. (2012). Plant species diversity for sustainable management of crop pests and diseases in agroecosystems: A review. Agronomy for Sustainable Development, 32(1), 273-303.

Rayburn, E. B., Blaser, R. E., & Wolf, D. D. (2007). Alfalfa plant measurements for yield prediction. Agronomy Journal, 99(5), 1415-1421.

Reddy, D. D. (2011). Integrated nutrient management for sustainable crop production and improving soil health. Indian Journal of Fertilisers, 7(12), 22–33.

Redin, M., Recous, S., Aita, C., Dietrich, G., Skolaude, A. C., Ludke, W. H. & Giacomini, S. J. (2014). How the chemical composition and heterogeneity of crop residue mixtures decomposing at the soil surface affects C and N mineralization. Soil Biology and Biochemistry, 78, 65-75.

Rekha, G. S., Kaleena, P. K., & Elumalai, D. (2018). Vermicompost enhances plant growth. Journal of Agricultural Science, 10(3), 45-52.

Roberts, C. A., Moore, K. J., & Johnson, K. D. (2009). Forage quality, yield, and persistence of grazing-tolerant alfalfa under continuous stocking. Crop Science, 49(2), 784-792.

Roy, S., Arunachalam, K., Dutta, B. K., & Arunachalam, A. (2016). Effect of organic amendments of soil on growth and productivity of three common crops viz. Zea mays, Phaseolus vulgaris and Abelmoschus esculentus. Applied Soil Ecology, 105, 42-50.

Sakamoto, T. (2012). Boron deficiency in alfalfa: Symptoms and correction. Journal of Plant Nutrition, 35(1), 169-181.

Sapkota, T. B., Majumdar, K., Jat, M. L., Kumar, A., Bishnoi, D. K., McDonald, A. J., & Pampolino, M. (2018). Precision nutrient management in conservation agriculture based wheat production of Northwest India: Profitability, nutrient use efficiency and environmental footprint. Field Crops Research, 227, 137-148.

Sayda, A. M., El-Shinnawy, M. M., & Abdel-Wahab, T. I. (2011). Economic efficiency of feed resources in dairy farms in Egypt. Journal of Animal and Poultry Production, 2(12), 693–705.

Scherer, H. W. (2001). Sulphur in crop production. European Journal of Agronomy, 14(2), 81-111.

Scherer, H. W. (2008). Sulfur in soils. Journal of Plant Nutrition and Soil Science, 171(3), 326-335.

Schwember, A. R., Schulze, J., Del Pozo, A., & Cabeza, R. A. (2019). Regulation of symbiotic nitrogen fixation in legume root nodules. Plants, 8(9), 333.

Sefa, S. (2017). Feed resources availability and livestock production in Ethiopia. Journal of Biology, Agriculture and Healthcare, 7(4), 1–8.

Sere, C., Steinfeld, H., & Groenewold, J. (2008). World livestock production systems: Current status, issues, and trends. FAO.

Seyoum, S., Bediye, S., & Tadesse, A. (2003). Feed resources in Ethiopia. Ethiopian Journal of Animal Production, 3(1), 1-20.

Sims, J. T., Bergström, L., Bowman, B. T., & Oenema, O. (2018). Nutrient management for intensive forage production. Agriculture, Ecosystems & Environment, 126(1-2), 1-3.

Singh, R., Sharma, R. R., & Kumar, S. (2016). Vermicompost improves strawberry yield. Bioresource Technology, 99(14), 8507-8511.

Singh, R., Sharma, R. R., & Kumar, S. (2019). Fertilization effects on forage protein. Journal of Plant Nutrition, 42(5), 512-525.

Smith, J. L., Collins, H. P., & Bailey, V. L. (2019). Fertilization reduces fiber content. Agronomy Journal, 111(1), 1-17.

Song, L., Jin, J., & He, J. (2021). Nitrogen fixation in alfalfa: Recent advances and future perspectives. Frontiers in Plant Science, 12, 683985.

Sulc, R. M., & Albrecht, K. A. (2020). Forage yield and quality trade-offs. Agronomy, 10(8), 1125.

Sun, Y., Ma, J., Sun, Y., Xu, H., Yang, Z., Liu, S., Jia, X., & Zheng, H. (2012). The effects of different water and nitrogen managements on yield and nitrogen use efficiency in hybrid rice of China. Field Crops Research, 127, 85–98.

Susan, E., Johnson, D. A., & Rumbaugh, M. D. (2016). Leaf to stem ratio in alfalfa as affected by management practices. Crop Science, 56(4), 2036-2044.

Sutar, R. K. (2009). Nutrient content of vermicompost prepared from different organic wastes. Karnataka Journal of Agricultural Sciences, 22(5), 1085-1086.

Suthar, S. (2009). Vermicomposting of vegetable-market solid waste using Eisenia fetida: Impact of bulking material on earthworm growth and decomposition rate. Ecological Engineering, 35(5), 914-920.

Sutton, M. A., Oenema, O., Erisman, J. W., Leip, A., van Grinsven, H., & Winiwarter, W. (2011). Too much of a good thing. Nature, 472(7342), 159–161.

Tadesse, M., Tana, T., & Dejene, M. (2020). Integrated use of organic and inorganic fertilizers for sustainable alfalfa production in moisture stress areas of Ethiopia. Crop Science, 60(4), 2105-2118.

Tandon, H. L. S. (1991). Sulfur research and agricultural production in India. The Sulfur Institute.

Tarawal, S. (1995). Forage yield estimation methods. FAO Agricultural Services Bulletin No. 23.

Teixeira, L. M., Crusciol, C. A. C., & Nascente, A. S. (2021). Alfalfa regrowth and persistence. Grass and Forage Science, 76(2), 189-201.

Tejada, M., & Gomez, I. (2015). Application of vermicompost in agriculture. Journal of Soil Science and Plant Nutrition, 15(4), 1077-1095.

Tekalign, T. (1991). Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa.

Terefe, B., Teshale, E., & Assefa, G. (2023). Crop residue utilization in mixed crop-livestock systems of Ethiopia. Tropical Animal Health and Production, 55(1), 1-12.

Tesfaye, A., & Animut, G. (2023). Nutritional value of pulse crop residues in Ethiopia. African Journal of Agricultural Research, 18(2), 123-135.

Tesfaye, Y., Mekuriaw, Y., & Tegegne, F. (2020). Utilization of brewer's grains in livestock feeding: The case of Ethiopia. Journal of Animal Science Advances, 10(3), 1673-1685.

Tibebu, K., Assefa, G., & Mengistu, S. (2018). Phenological development of alfalfa varieties in central Ethiopia. Ethiopian Journal of Agricultural Sciences, 28(2), 45-60.

Tolera, A., Berg, T., & Sundstøl, F. (2012). The effect of feeding alfalfa hay on milk yield and composition of dairy cows. Livestock Science, 147(1–3), 171–176.

Tomic, Z., Sokolovic, D., & Markovic, J. (2001). Alfalfa quality as affected by cutting management. Biotechnology in Animal Husbandry, 17(5-6), 229-236.

Towedros, M., Tesfaye, K., & Mohammed, H. (2014). Vermicomposting in Ethiopia: Current status and future prospects. African Journal of Agricultural Research, 9(53), 3863-3872.

Tucak, M., Popović, S., & Čupić, T. (2020). Alfalfa yield under different management. Agronomy, 10(8), 1125.

Turan, M. (2017). Alfalfa production in Turkey. Turkish Journal of Agriculture and Forestry, 41(3), 189-198.

Undersander, D., Cosgrove, D., Cullen, E., Grau, C., Rice, M. E., Renz, M., ... & Sheaffer, C. (2020). Alfalfa management guide. NRAES, 1-40.

Van Reeuwijk, L. P. (1992). Procedures for soil analysis (3rd ed.). ISRIC.

Van Soest, P. J., & Robertson, J. B. (1985). Analysis of forages and fibrous foods. Cornell University Press.

Vijay, D., Gupta, N., & Gupta, S. (2015). Regrowth potential of alfalfa. Forage Research, 41(1), 1-6.

Vishal, G., & Duhan, A. (2013). Biomass accumulation in alfalfa. Journal of Forage Research, 3(2), 89-94.

Voisin, A. S., Guéguen, J., Huyghe, C., Jeuffroy, M. H., Magrini, M. B., Meynard, J. M., & Pelzer, E. (2014). Legumes for feed, food, biomaterials, and bioenergy in Europe: A review. Agronomy for Sustainable Development, 34(2), 361–380.

Waile, A., Assefa, G., & Mengistu, S. (2016). Alfalfa quality in central Ethiopia. Ethiopian Journal of Animal Production, 16(1), 1-12.

Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. Soil Science, 37(1), 29-38.

Wang, J., Li, X., Zhang, J., Yao, T., & Wei, D. (2023). Vermicompost improves alfalfa growth and nutrient uptake through microbial community modulation. Frontiers in Microbiology, 14, 1125634.

Wayu, S., & Atsbeha, E. (2019). Alfalfa management in northern Ethiopia. African Journal of Agricultural Research, 14(5), 234-243.

Workiye, T., Assefa, G., & Feyissa, F. (2021). Rainfed alfalfa production in Ethiopia. Tropical Grasslands, 9(1), 45-58.

Yadav, R. K., Singh, S. P., & Lal, D. (2023). Boron management in alfalfa: Avoiding toxicity while correcting deficiency. Journal of Plant Nutrition, 46(1), 1-15.

Yang, C., Yang, L., Yang, Y., & Ouyang, Z. (2010). Alfalfa benefits to subsequent crops: A review. Agronomy Journal, 102(1), 1-8.

Yuan, L., Huang, J., Li, X., & Christie, P. (2021). Sulfur deficiency in alfalfa: Diagnosis and correction. Journal of Plant Nutrition, 44(5), 729-744.

Zeinab, A. H., El-Kady, E. A., & Mohamed, M. S. (2013). Alfalfa yield under Egyptian conditions. Journal of Animal and Poultry Production, 4(7), 423-434.

Zewdie, W. (2010). Seasonal variation in the availability and nutritive value of feed resources for livestock in the central highlands of Ethiopia. Livestock Research for Rural Development, 22(6).

Zhang, W., Liu, D., Li, C., Cui, Z., Chen, X., Russell, Y., & Dou, Z. (2020). Phosphorus fertilization strategies for alfalfa production in China. Field Crops Research, 246, 107682.

Zhang, X., Li, H., He, J., Wang, Q., & Golberg, M. (2023). Vermicompost enhances alfalfa yield and quality through improved nutrient cycling. Agronomy Journal, 115(2), 789-803.

Zubair, M., Hussain, N., & Ahmad, B. (2024). Integrated nutrient management in mungbean. Journal of Plant Nutrition, 47(3), 1-15.

7. Appendix

Layout out of the plot

	B1		**B2**		**B3**		
	P1	T6 NP=50	P32	T10 NP=100	P33	T12 NP=100	
		V=2.5		V=2.5		V=7.5	
	P2	T12 NP=100	P31	T16 NP=150	P34	T9 NP=100	
		V=7.5		V=7.5		V=0	
	P3	T8 NP=50	P30	T9 NP=100	P35	T2 NP=0	
		V=7.5		V=0		V=2.5	
	P4	T5 NP=50	P29	T6 NP=50	P36	T14 NP=150	
		V=0		V=2.5		V=2.5	
	P5	T3 NP=0	P28	T11 NP=100	P37	T15 NP=150	
		V=5		V=5		V=5	
	P6	T14 NP=150	P27	T4 NP=0	P38	T10 NP=100	
		V=2.5		V=7.5		V=2.5	
	P7	T15 NP=150	P26	T7 NP=50	P39	T5 NP=0	
		V=5		V=5		V=5	
	P8	T2 NP=0	P25	T15 NP=150	P40	T5 NP=50	
		V=2.5		V=5		V=0	
	P9	T10 NP=100	P24	T5 NP=0	P41	T6 NP=50	
		V=5		V=0		V=7.5	
	P10	T16 NP=150	P23	T13 NP=150	P42	T1 NP=0	
		V=75		V=0		V=0	
	P11	T11 NP=100	P22	T5 NP=50	P43	T13 NP=150	
		V=5		V=0		V=0	
	P12	T13 NP=150	P21	T14 NP=150	P44	T11 NP=100	
		V=0		V=2.5		V=5	
	P13	T1 NP=0	P20	T8 NP=50	P45	T4 NP=0	
		V=0		V=7.5		V=7.5	
	P14	T9 NP=100	P19	T12 NP=100	P46	T7 NP=50	
		V=0		V=7.5		V=5	
	P15	T7 NP=50	P18	T2 NP=0	P47	T16 NP=150	
		V=5		V=2.5		V=7.5	
	P16	T4 NP=0	P17	T3 NP=0	P48	T6 NP=50	
		VP=7.7		V=5		V=25	

Figure 2 Land Preparation

Figure 3 Perepaerd bade

Figure 4 Seed Sowing

Figure 5 After sowing performance

Figure 6 Management of Plot

Figure 7 Visiting the Field with My Advicor

Figure 8 The performanc of Alfalfa for 50% flowering stage

Figure 9 measuring height of the plant

Figure 10 First Cut

Figure 11 Measuring the weight of sample

Figure 12 Sample preparation in the laboratory