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Review Article

Role of Forage Legumes in Enhancing Soil Fertility and Livestock Nutrition in Ethiopia

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Abstract

Legume forages are plants from the legume family that are grown primarily for animal feed, rather than for their seeds. Legumes have a special ability to convert atmospheric nitrogen into a form that plants can use, thanks to symbiotic bacteria in their root nodules. Legumes are rich in protein, which is essential for the growth and development of livestock; hence, including legumes in animal feed can enhance the overall nutrition of the animals and have high digestibility, making them an efficient and effective component of animal diets. These plants can be harvested and used as hay, silage, or pasture. The high protein content of legumes makes them particularly valuable in animal nutrition. Common legume forages include alfalfa, clover, vetch, and various types of peas and beans. Therefore, the objective of this review is to investigate the integration of legumes into Ethiopian forage systems and their contribution to soil fertility improvement and livestock nutrition. Furthermore, their high protein content and ability to fix nitrogen in the soil contribute to sustainable agricultural practices, making them an essential component of modern farming systems. This dual benefit not only supports livestock health but also promotes long-term soil fertility.

Keywords

Feed, Legume, Organic Matter, Nitrogen, Soil

1. Introduction

Forage legumes contribute to sustainable crop production apart from nutritional security for the livestock. Forage legumes are crucial for human nutritional security, as they are an integral component for increased availability of animal protein and products with higher biological value compared to plant proteins. The inclusion of forage legumes in crop production systems is more useful as these can not only provide food and feed to animals but also improve soil productivity and act as soil-conserving components of agricultural and agroforestry systems [10]. In the coming decades, ensuring food security for Ethiopians will face great challenges. The linkage in mixed crop-livestock production systems through feed resources particularly legumes which fix N, and provide high quality feed, can enhance both the level and rate of nutrient cycling in the system, leading to increased soil fertility, improved animal nutrition, and increase the overall production and protect the environment, especially where land resource is limited [8]. Legume forages are plants from the legume family that are grown primarily for animal feed, rather than for their seeds. These plants can be harvested and used as hay, silage, or pasture. The high protein content of legumes makes them particularly valuable in animal nutrition. Common legume forages include alfalfa, clover, vetch, and various types of peas and beans. Legume crops contribute to agri-

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cultural sustainability by providing high-quality food, reducing greenhouse gas emissions, sequestering carbon in soils, increasing crop diversity, and reducing external inputs [17]. Legume crops could play an important role in this context by delivering multiple services in line with sustainability principles. In addition to serving as a fundamental, worldwide source of high-quality food and feed, legumes contribute to reducing the emission of greenhouse gases, as they release 5-7 times less GHG per unit area compared with other crops; allow the sequestration of carbon in soils [4]. Their ability to fix nitrogen, add organic matter, and improve soil structure makes them invaluable in sustainable farming. Plus, their high nutritional value for both humans and livestock means they contribute to food security and agricultural resilience.

Legumes are not only beneficial for the soil but also offer a range of advantages for grazing livestock. The high protein content in legumes, compared to grasses, can significantly improve the nutritional quality of forage, leading to better animal health and productivity. Moreover, the integration of legumes into pasture systems offers a win-win scenario for both soil and animal health [17]. Cereal-legume diversification and intensification-based cropping systems are a key and potential driving approach towards sustainable intensification of crop-livestock farming systems, particularly in the Ethiopian context. However, Production of grain legumes has not been given similar attention to cereal crops, and as a result, legume production techniques at the farmer's level have made little progress [22]. Therefore, the objective of this assessment is to investigate the integration of legumes into Ethiopian forage systems and their contribution to soil fertility improvement and livestock nutrition.

Review Materials and Methods

Different research articles have been collected from around fifty research articles and previous review material with the keywords of legume, soil, feed, organic matter, and Nitrogen. The information was gathered through a systematic review method. The Source of material was Web of Science, PubMed, journal articles, previous reviews, and related Google Scholar.

2. Literature Review

2.1. Role of Legumes in Enhancing Soil Fertility in Ethiopian Forage Systems

Legumes are essential in enhancing soil fertility due to their unique ability to fix atmospheric nitrogen. According to [8], legumes are recognized for their capacity to fix atmospheric nitrogen through symbiotic relationships with rhizobia bacteria, which transform atmospheric nitrogen into a form that plants can utilize and enrich the soil with this vital nutrient. This study is similar to the study of [5] showed that the most environmentally friendly method of supplying the massive amounts of nitrogen needed through legumes to create high-yielding crops with excessive protein content. Biological nitrogen fixation (BNF) not only helps the legume to fulfill its nitrogen need but also enriches the soil nitrogen status to improve the succeeding crop yield [15]. Plants get nitrogen from soil either through the decomposition of legume residue on their incorporation or from atmospheric nitrogen fixation through leguminous plants.

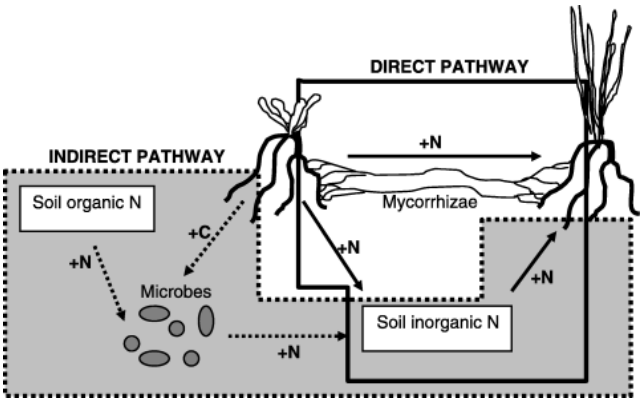

Figure 1. *How defoliation can increase soil nitrogen availability through direct and indirect pathways.*

2.1.1. Legumes in Improving Soil Organic Matter

Legume plants contribute to the organic matter content of the soil through their residues (leaves, stems, roots). Mixed crop-livestock farming systems in the highlands of Ethiopia are constrained by animal feed shortage and land degradation in the form of soil erosion and nutrient depletion, resulting in low agricultural productivity [8]. Leguminous intercrops can reduce N2O emissions and methane uptake in maize production, supporting climate-smart agriculture goals while intensifying crop production in the Great Rift Valley, Ethiopia. This research aligns with [22], who highlighted that integrating legumes into cropping systems enhances soil fertility and boosts crop yields. The root systems of legumes help to break up compacted soils and improve soil aeration, which promotes better root growth for subsequent crops [22]. Moreover, legumes play a pivotal role in rejuvenating soil organic matter and addressing problems when included in crop rotations with non-leguminous crops. This study indicates that a legume improves soil organic matter more than cereal crops due to its morphological characteristics and decomposition. This enhanced soil quality not only supports better nutrient availability for subsequent crops but also promotes a more resilient ecosystem. As a result, integrating legumes into agricultural practices can lead to sustainable farming systems that benefit both the environment and crop yields.

2.1.2. Legumes in Soil Structure Improvement

The roots of legumes help improve soil structure by breaking up compacted soil, which enhances water infiltration and root penetration for subsequent crops [3]. According to

this author, lablab and cowpea enhanced soil chemical properties (N, P, and K) in southern Ethiopia, while maize stover and grain nitrogen yields showed no significant improvement. This is due to their biological nitrogen-fixing capacity compared to grass plants.

2.1.3. Legumes in Carbon Sequestration

The process involves capturing atmospheric CO2 and incorporating it into the soil through plant activity. Legumes have the potential to reduce the CO2 emitted during the manufacturing of chemical nitrogenous fertilizers through their biological nitrogen fixation (BNF) capacity [19]. According to [19] the notion that in resource-constrained smallholder croplands, combining 50-75% crop residue retention, no-tillage, and higher nitrogen fertilizer can greatly boost soil organic carbon sequestration.

2.1.4. Legumes in Crop Diversification

Ethiopian smallholder farmers have developed diverse legume varieties, but community-level conservation is needed to ensure their sustainability and adaptability to changing agroecological conditions [8]. Compatibility of forage legumes with grasses depends on the morphology and physiological characteristics of the legumes and grass, in combination with the response of each to management imposed and the climate, soil, and biotic conditions under which the crop is growing [8]. There are various strategies to integrate forage legumes into crop-livestock farming systems. The method of integration used for a specific farming system mainly depends on the type of forage crops, food crops, soil type, rainfall pattern, and other social and economic factors. Over-sowing forage legumes in the natural pasture improves its botanical composition, forage yield, forage quality, and soil fertility.

2.1.5. Role of Legumes in Animal Nutrition in Ethiopian Forage Systems

Legumes are rich in protein, which is essential for the growth and maintenance of livestock. Since legumes are rich in protein (15-23%), especially in the leaves (over 25%), they are the most important source of crude protein in roughage. Legume forage, like vetches, is an important feed source for animals as a supplement to low-quality feeds [8]. Tropical grasses were of lower quality than their temperate counterparts, and the introduction of adapted legumes into tropical grazing systems would simultaneously address the problem of the low N status of leached tropical soils cited by There is an emerging and significant role for legumes as a protein supplement to reduce reliance on expensive concentrates, which often account for a high proportion of direct costs.

2.1.6. Legumes Improve Digestibility

Legumes have higher digestibility than grasses, making the nutrients more accessible to livestock [4]. According to [4], the higher intake of legume silages reflects differences in the cell structure of legume plants, which, combined with high fermentation rates, means that they break down into small particles in the rumen and leave the rumen more rapidly than perennial ryegrass. In addition to this, legumes are indeed known for their higher palatability compared to grass feeds, often due to their higher protein content and better digestibility.

2.1.7. Legume Fiber Content

The quality of forage feed is mostly affected by its maturity rather than any agronomic factor. However, it can be improved through different management mechanisms, like harvesting at appropriate stages. The structural plant cell will increase as the maturity of the plant advances. Late-harvested forage can have high fiber content due to its structural cell wall-like hemicellulose and lignin indigestible accumulation. Hence, cell wall material is the primary constituent of forages. The main objective of forage chemical evaluation is to characterize its cell wall fiber. According to the findings of [12], fodder having lower fiber content is often considered a nutritionally rich fodder for livestock. Fodder quality and fiber fractions are indirectly related to forage composition. The low fiber content indicates a higher fodder quality than the maximum content. Since the fiber is a less digestible and anti-nutritional factor of livestock feed. Legumes have lower fiber content than grasses. Excessive fiber can be difficult for animals to digest, so lower fiber content improves overall digestibility. Dietary fiber (DF) was considered an antinutritional factor due to its adverse effects on feed intake and nutrient digestibility [7]. Consistently, the work by [1] highlights these crucial benefits effectively. Accordingly, feed intake, digestibility, and feed value are all influenced by the density of fiber in the fodder. The fodder quality, in terms of fiber concentration, determines the intake, digestibility, and feed value of the fodder. Therefore, it is recommended to avoid feeding high-fiber content to livestock. This means that legumes have lower fiber content compared to other cereal crops due to their morphological characteristics.

2.1.8. Legumes as Anti-nutritional Factors

Some forage contains anti-nutritional factors that can hinder digestion. Legumes generally have fewer of these factors, making them easier for animals to digest. These attributes make legumes an excellent addition to the diet of livestock, enhancing not only digestibility but also overall animal health and productivity [13]. Excessive fiber can hinder digestibility in various animal species, as evidenced by research indicating that lower fiber content enhances nutrient absorption and overall digestive efficiency. For instance, a study by [14] showed that in poultry, dietary fiber has been traditionally viewed as an antinutritional factor; however, moderate fiber levels can enhance gut health and nutrient absorption [9]. However, with increasing evidence, scientists have found that DF has enormous impacts on the gastrointestinal tract (GIT) development, digestive physiology, including nutrient diges-

tion, fermentation, and absorption processes of poultry. Increasing DF content benefits digestive physiology by stimulating GIT development and enzyme production. And the inclusion of fiber at a moderate level in diets also alters poultry growth performance. In contrast, the study by [9] indicated that the fiber content of cereal forage is a critical factor influencing its digestibility and overall quality for livestock. The composition of fiber, particularly neutral detergent fiber (NDF) and acid detergent fiber (ADF) varies significantly depending on the growth phase of the forage. This variability is essential for understanding the nutritional value of different cereal forages. The fiber content increases as cereal grasses mature. For instance, NDF content ranges from 50-55% before eating to 70-72% during flowering, while ADF content rises from 31-32% to 40-45% in the same phases [18]. According to this review, Cereal with legume intercropping can balance fiber and protein concentrations, enhancing forage quality without compromising the overall nutrient profile [17]. Fiber content is crucial for optimizing livestock nutrition. It is also important to consider the balance between fiber and other nutrients, as excessive fiber can lead to reduced energy availability in forages. Hence, an inclusive approach to forage management is necessary to ensure optimal livestock health and productivity.

2.1.9. Multiple Agroecosystem Services of Forage Legumes Towards Agriculture Sustainability

As a feed, forage legumes can effectively support the adequate amounts and characteristics needed for various productive animals [11]. Hence, the inclusion of legume forages in cropping systems is inevitable in advancing soil sustainability and food and nutritional security without compromising the long-term soil fertility base of the soil resources. According to [10] the production of high-quality fodder is also crucial for livestock because feed alone accounts for 60-70% of the cost of producing milk. This study implies that forage legumes are not only agriculturally sustainable but also have a great production potential.

2.2. Nutritional Benefits of Forage Legumes in Livestock Systems

The use of forage legumes containing some bioactive compounds (mainly phenols, terpenes, and alkaloids) is particularly promising as they have shown potential benefits in multiple dimensions throughout the ruminant production chain. In addition to being protein-rich resources, they have been shown to decrease nitrogen fertilization, reduce methane emissions and urinary nitrogen excretion, have anthelmintic and antioxidant activities improving the health status of animals, and can improve product quality through their fatty acid profile and oxidative stability [15]. Animal performance, including milk production and growth rate, depends on the quality of feeds, especially the forage available to the animal. The main determinants of forage quality are nutrient concentrations (crude protein and fibers), intake, digestibility, and partitioning of metabolized products within animals. Antinutritional factors (ANFs) are a major factor reducing the wider use of underutilized legumes as human food and animal feeds [16]. Most of these attributes are shown to be strongly affected by plant species, plant morphological fractions, environmental factors, and stage of maturity [4]. These studies suggest that forage legumes provide nutritional benefits to livestock systems by improving protein content, enhancing nutrient intake and digestibility, reducing environmental impacts, and offering economic advantages over grass-based systems.

2.2.1. Legume Crops and Livestock Health in Ethiopia

The livestock sector in Ethiopia has historically contributed about 11% to the national GDP and 24% to the agricultural GDP. Despite this, the sector faces serious challenges, including reduced productivity and the impact of infectious diseases, which are major contributors to economic loss. Ruminants account for 80% of the national herd and contribute significantly to poverty alleviation, with small ruminants (defined as domesticated sheep and goats) being key to the improvement of the income status of female smallholder farmers. Between 1995 and 2005, livestock contributed on average to 11% of the national GDP of Ethiopia, and 24% of the share of GDP from agriculture [8].

Legume crops play a significant role in Ethiopia's agriculture, contributing to food security, soil fertility, and livestock health. Legumes like chickpeas, lentils, and soybeans are widely cultivated and are essential for crop rotation, as they improve soil nitrogen levels through nitrogen fixation. For livestock, legumes serve as a valuable source of forage, providing protein-rich feed that enhances animal health and productivity. However, challenges such as limited access to quality seeds, lack of mechanization, and gaps in agronomic practices hinder the full potential of legume cultivation [20]. In Ethiopia, the integration of legume crops into livestock farming systems plays a crucial role in enhancing livestock health and agricultural productivity. Legumes not only provide high-quality feed for livestock but also improve soil fertility through nitrogen fixation, which is essential for sustainable agriculture in the region. Legume crops, such as Biserrula pelecinus and soybean, are valuable for their high protein content, which is essential for improving the nutritional quality of livestock. These legumes can be used for grazing, hay, or silage, providing a nutritious alternative to low-quality crop residues commonly used during the dry season. Soybean has great potential as a high-protein and nutritious forage in Ethiopia, potentially addressing feed scarcity and improving livestock development. Continuous cereal-based mono-cropping practices, soil fertility depletion and erosion problems, limited improvement and farmers' preferred legume varieties, lack of/limited access to quality seeds and no/or minimal uses of inputs in legume production, limited promotion of appropriate legume technologies, wrong

farmers' perceptions for legumes'input uses are the most important constraints of legume intensification in the country.

In addition, problems of institutional setup, limited availability of value-adding processing machines for legume products, policy and strategy gaps on legume based intensification; inappropriate market information and unclear legume market outlets, weak public and private partnerships across each legume commodity are also common bottlenecks in Ethiopia [21]. Hence, revising existing extension systems, especially focusing on the promotion and popularization of legume intensification, is the focus of policy advice.

Maximizing the extension of legume intensification; strengthening the current farmers' soil conservation practices and soil fertility management options; encouraging and supporting use of inputs for legumes; supporting legume quality seed production and supply by different seed producers; designing clear legume value chain strategies to develop sustainable market outlets; encouraging communities to consume legumes for improved nutrition; and revising the existing livestock production policy and/or strategy, particularly to develop a strategy to enhance the legume productivity are key areas for future intervention priorities. Establishing a standard regulatory authority to ensure sustainable supplies of standard-quality legume products is also critical to maximize the national benefits of legume production and marketing. Efforts are being made to address these issues through strategies like the National Legume Crop and Livestock Strategy and Agricultural Growth and Transformation Plans, which aim to improve legume production and integrate them into mixed farming systems. However, there is much concern about legume crops with livestock utilization that needs deep consideration. Hence, more attention to the legume sector in government policy, strategy, and guidelines is the most important gap that must be addressed to enhance legume-based intensification. Increasing the extension of legume intensification (particularly forage legumes), encouraging and supporting use of inputs, supporting quality seed production and supply by different seed producers, developing clear legume value chain strategy to ensure sustainable market outlets, encouraging the consumption of legumes for improved nutrition, and revising the existing livestock production policy and/or strategy are the main areas that need to be addressed by different legume value chain actors to boost the sector contributions to livelihoods and the economy.

2.2.2. Role of Forage Legumes in Sustainable Agriculture

The role of forage legumes in sustainable agriculture is fundamental to enhancing productivity while minimizing environmental impacts [2]. The integration of forage legumes into agricultural systems provides multifaceted benefits, including nitrogen fixation, improved soil health, increased biodiversity, and enhanced forage quality for livestock. Forage legumes, such as alfalfa (Medicago sativa) and red clover, play a pivotal role in sustainable agricultural practices by promoting soil health through organic nitrogen addition. These legumes establish symbiotic relationships with rhizobia, allowing them to convert atmospheric nitrogen into a bioavailable form, which reduces dependency on synthetic nitrogen fertilizers. One primary benefit of forage legumes is their ability to fix atmospheric nitrogen through a symbiotic relationship with specific rhizobia bacteria. This biological nitrogen fixation reduces the need for synthetic fertilizers, which are often costly and environmentally harmful. Studies have shown that legumes can substantially enhance soil nitrogen levels, benefitting subsequent crops and promoting better overall soil fertility [6]. The benefit of intercropping perennial and annual forage cultivation along with a year-round cereal legume based cropping system adds value to the livestock production system [12]. Legumes support sustainable grassland production through nitrogen fixation and increased yields.

3. Summary and Conclusions

3.1. Conclusions

Legumes have a special ability to convert atmospheric nitrogen into a form that plants can use. This process naturally enriches the soil with nitrogen, reducing the need for synthetic fertilizers. The roots of legumes help improve soil structure by increasing organic matter, promoting aeration, and enhancing water infiltration. Legumes are rich in protein, which is essential for the growth and development of livestock. Including legumes in animal feed can enhance the overall nutrition of the animals and have high digestibility, making them an efficient and effective component of animal diets. In essence, legumes play a crucial dual role in sustainable agriculture by enriching the soil and providing high-quality nutrition for livestock. From this conclusion, it is generally inferred that establishing a legume forage system related to other cereal crop production in Ethiopia is mandatory. Most organic systems are built on nitrogen-fixing legume-based leys, whether they are utilized for conservation, grazing, or mulching to increase soil fertility. Because of a lack of consciousness, inadequate extension services, cooperation, national capacity building, and support from policymakers and non-governmental organizations to promote forage systems in Ethiopia have not yet been taken into consideration.

3.2. Recommendations

Based on this investigation, the following views are forwarded:

1) Ethiopia possesses significant potential for forage production, particularly with leguminous forage crops, due to its favorable environmental conditions. However, the combination of forage and cereal food crops is not practiced in Ethiopia. Therefore, it has to be practiced in the future.

2) According to this review, there are limitations on: thoughtful legume plant production, utilization, legume as environmental conservation, carbon sequestration, nitrogen fixation, soil fertility, and providing high-quality feed for sustainable livestock production.
3) Therefore, raising awareness within the community is essential.
4) Poor collaboration among stakeholders can indeed hinder sustainable livestock and agricultural production.
5) When farmers, researchers, policymakers, and other key players fail to work together effectively, it can lead to inefficiencies, resource wastage, and missed opportunities for innovation.
6) In all for sustainable agriculture, livestock production, and environmental health, developing integrated methods such as intercropping, grass-legume mixtures, and combining legumes with other food crops should be the future focus.

Abbreviations

NDF	Neutral Detergent Fiber
GDP	Gross Domestic Product
ADF	Acid Detergent Fiber
GIT	Gastrointestinal Tract
DF	Dietary Fiber
BNF	Biological Nitrogen fixation

Conflicts of Interest

The Author declare no conflicts of interest.

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