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5. Legume Forages: A Multidisciplinary Approach for Ensuring Agricultural Sustainability and Global Food Security under Altered Climate Conditions

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Abstract:

In addition for providing the livestock' nutritional needs, forage legumes help to ensure the long-term viability of crop production. Increased availability of animal protein and products with better biological value than plant proteins makes forage legumes an essential component for human nutritional security. Because of their ability to increase soil productivity and serve as soil-conserving components in agricultural and agroforestry systems, forage legumes are an especially valuable addition to crop production systems. Forage crops, especially leguminous forages, require some attention due to the overall relevance of the production system and the severe lack of these resources. Hence, careful evaluation is required to ascertain the course and scale of transformation in agricultural management practice with feed legume additions. When used as a feed, forage legumes can increase production levels and improve animal health in a variety of ways. These agricultural crops possess the potential to facilitate the achievement of our objectives pertaining to food and fodder security, as well as environmental sustainability, while ensuring the preservation of long-term viability. Hence, the inclusion of forage legumes in cropping systems is crucial as it can contribute to the restoration of soil fertility, enhancement of soil biology and biodiversity, fixation of atmospheric nitrogen, reduction of fertilizer requirements, carbon sequestration, mitigation of climate change, improvement of soil carbon sequestration, and neutralization of the adverse effects of climate change. This chapter provides a comprehensive overview of the possible contributions of forage legumes in several aspects of animal nutrition, soil sustainability, food and nutritional security, soil fertility enhancement, nitrogen fixation, soil biology and biodiversity, carbon sequestration, climate change mitigation, and other ecological services.

Keywords:

Forage Legume, Carbon sequestration, Livestock and Food security.

5.1 Introduction:

Forage crops, which are typically grown for grazing purposes and known to supply quality feed for grazing animals that can play an important role in the cattle industry (Jana *et al.*, 2022). These crops can be thought of as an essential component for cultivators, one that links the agricultural and veterinary fields. India has grown rapidly over the past few decades, passing the United States to become the world's leading milk producer (209.96 million tonnes in 2020-21, compared to 146.31 million tonnes in 2014-15; annual growth rate of 6.2%; Economy Survey 2020-21, 2021).

This can help India provide food, nutritional security, and economic returns to a growing global population. Legume forages are a ten times cheaper supply of critical feed ingredients compared to other feed sources (Kumar *et al*., 2016, Rehman& Raja., 2020), and are well recognized as a superior source of nutrition for dairy cattle.

Forage crop cultivation, however, has many other uses, including providing a living fence, bee forage, fuel wood, food, enhancing soil nutrient status, creating wildlife habitat, increasing self-sufficiency, nutrient cycling, and farm diversification.

In India, there is currently a deficit of 36% in green fodder, 11% in dry crop leftovers, and 44% in concentrate feed ingredients due to the fact that fodder crops are using almost 5.4% of the country's total arable area. It is estimated that there are 650 different genera and 18,000 different species of cultivated legumes in the world. For domestic animal consumption, only roughly 60 of these forage legume species have been farmed (Schultze *et al.,* 2018).

By changing the atmospheric concentration of greenhouse gases (GHGs) such methane, carbon dioxide, and nitrous oxide, climate change has had dramatic effects on human society and the natural environment worldwide (IPCC 2019). A reduction in the protein content of widely used forage crops has been reported, and while climate change is a continuous process on Earth, its frequency has increased rapidly in the last century or so (Xu *et al.,* 2021).

This will have a negative impact on livestock production in terms of both quantity and quality of green biomass. As a result of the negative effects of climate variability (temperature and rainfall) and climate-driven extremes (flood, drought, heat stress, cold waves, and storms) on crop and livestock production, food security has become an issue of paramount importance.

These extremes have the potential to have far-reaching social and economic consequences, including decreased incomes and livelihoods, and even negative health effects. Incorporating nitrogen-rich forage legumes into crop production systems can benefit not only the soil but also the crops that are grown alongside or after them in a rotation, making them an invaluable feed source for livestock.

This could help provide a long-term solution to the problem of global food and protein insecurity. By improving soil organic matter, soil porosity, recycling nutrients, improving soil structure, lowering soil pH, modifying the efficiency of soil biological activities, and prevents the buildup of disease occurrence and weed growth. Thus, the forage legumes have tremendous potential for increasing sustainability through soil quality remuneration (Mahanta *et al.,* 2009) act as sources of animal feed, stabilizing global food security and having positive synergistic impacts on soil biology, fertility, biodiversity.

5.2 Role of Forage Legumes in Livestock Production:

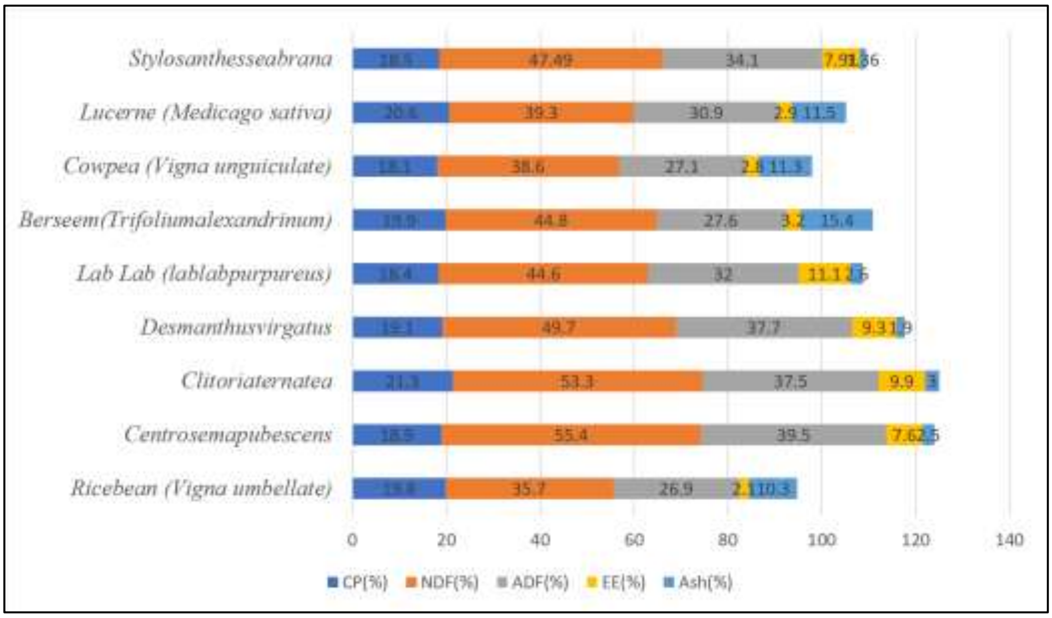
The livestock industry plays a crucial role in the global agricultural sector, with a primary focus on enhancing economic conditions, ensuring food and nutritional security, and improving the livelihoods of about 75 percent of the global farming population. Based on the 20th Livestock Census conducted in 2019, India has emerged as the country with the highest animal population, with approximately 535.82 million animals recorded and this figure reflects a 4.6% increase compared to the previous census conducted in 2012. Furthermore, India holds a prominent position in milk production, contributing 209.96 million tonnes, which accounts for 23% of global production. This makes milk the second most valuable agricultural commodity in India, after rice, and plays a significant role in contributing to the Gross National Product (GNP). The maintenance of forage quality is influenced by several essential aspects, including the concentrations of nutrients such as crude protein and fibers, the consumption of forage by animals, the digestibility of the forage, and the partitioning of metabolic products within the animals (Lee, 2018).

Forage legumes are known to possess superior nutritional value compared to grass species. They have the potential to enhance the nutritive value of herbage, as opposed to grass monocultures, due to their ability to maintain digestibility at a slower rate as they mature, as well as their higher quality protein content (Dewhurst *et al.,* 2009; Kumar *et al.*, 2016).The inclusion of legumes in the diet of dairy cattle contributes to a balanced nutritional profile. By incorporating legumes into the animal feed, the resulting diet becomes more digestible and has a higher nutritive value. This, in turn, promotes increased levels of production, specifically in terms of weight gain, among livestock. The consumption of fibrous fodder is primarily influenced by the degree of rumen fill, which, in turn, is directly associated with the rate of digestion and movement of fibrous particles from the rumen (Huhtanen *et al.,* 2016).

The palatability of a feed has been associated with both its physical attributes and the availability of certain components that might influence taste and hunger, such as proteins, lipids, and soluble carbohydrates. The use of legume forages in the feeding plan has the potential to address nutritional deficiencies. The significance lies in the disparities in cation exchange capacity between cereal and legume crops, with the latter exhibiting a larger capacity. Consequently, this higher capacity results in an increased accumulation of multivalent micronutrients in legume crops. Moreover, the inclusion of forage legumes in livestock feed is beneficial due to their higher crude protein (CP) content compared to cereals. This is attributed to the symbiotic relationship between legumes and Rhizobium, which enhances the nitrogen supply to legumes. The increased palatability and digestibility of forage legumes contribute to improved forage intake by livestock and subsequently enhance animal performance. The cost of milk production is mostly attributed to feed expenses, which account for roughly 50% of the total cost. Enhancing the quality of forage has been identified as a viable approach to enhance animal productivity and thus improve overall feeding efficiency. Leguminous forages possess the capacity to enhance the nutritional quality of ruminant diets due to their elevated crude protein (CP) concentration and reduced fiber content when compared to grass and cereal forages. The cell wall composition of legume plants differs from that of grass species, with legumes containing a higher proportion of uncommon hemicelluloses and pectin. This variation in cell wall composition has been found to enhance animal digestion. The study conducted by Dalgliesh et al. (2010) examines the importance of legume fodder in animal performance. The findings indicate that animals fed with forage legumes exhibited a daily live weight gain of 230 g, whereas those fed with leucaena shown a higher rate of 290 g per day. The determination of the digestibility of forage crops is reliant upon the content of carbon-based nutrients, which are aided by minerals and vitamins, in their provision to animals (Capstaff & Miller, 2018). The study conducted by Chanthakhoun *et al*. (2010) found that the inclusion of rice bean hay in buffalo diets resulted in an increase in cellulolytic rumen bacteria. This increase in bacteria was reported to aid in the digestion and utilization of high fiber feeds.

Furthermore, it should be noted that plant secondary metabolites, including tannins and phenols, play significant roles in the defense against various stresses, both biotic and abiotic. These metabolites also have an impact on the digestibility of fodder and ultimately influence the production of cattle. Hence, there exists a pressing demand for high-quality forage crops that can enhance livestock productivity, promote human health, and yield economic advantages for growers (Singh *et al*., 2018; Varijakshapanicker *et al*., 2019).

Table 5.1: Nutritional profile of some of the important forage legumes



Trivedi (2002)

5.3 Potential Benefits of Adopting Forage Crops in Crop Production Systems:

Long-term maintenance of soil fertility and productivity can be achieved through including forage legumes in cropping practices. These systems can fix atmospheric nitrogen biologically, which has a positive effect on the yield of subsequent crops in rotation. However, the decomposition of legumes' root and shoot wastes releases both macro (N, P, and K) and micro (Zn, Fe, Mn, and Cu) nutrients from the soil, lowering the need for nitrogenous fertilizer. Increased carbon sequestration and decreased emissions of greenhouse gases are both benefits of legumes.

Soil fertility and carbon sequestration improve together, as more biomass is produced. Also, compared to other crops, legumes produce 5-7 times fewer greenhouse gas emissions per acre, facilitate the absorption of carbon in soils, and lead to a reduction in fossil energy inputs. Soil carbon sequestration occurs when legume plants in pasture boost aboveground biomass production, which in turn ensures a larger soil carbon pool and greater soil fertility (Coonan *et al.,* 2019).

Intercropping forage legumes is widely regarded as an efficient method of forage production due to its ability to decrease weed growth, increase land use efficiency, and decrease the prevalence of soil-borne diseases (Tamta *et al*., 2019).

Furthermore, it improves soil bulk density and moisture retention capacity by increasing infiltration rate and decreasing surface runoff, yielding better results in preventing soil erosion. Soil improvement occurs due to cycling of minerals from deeper soil layers and enhanced concentration of soil organic matter through litter production when deep-rooted, infertile-soil-adapted legumes like *Stylosanthes* spp., *Macrotylomaaxillare*, and *Flemingia* spp. are introduced to degraded areas (Boddey *et al*., 2015).Rotating biennial and perennial legumes with shallow-rooted crops can reduce nutrient loss from leaching below the crop root zone because the legumes' deep roots recycle agricultural nutrients in the soil profile (Mohammadi *et al.,* 2012).

Soil with a larger percentage of organic matter and a more solid structure, like that created by legumes, is less likely to be eroded by wind or water. Glomalin, a protein produced symbiotically by legume roots, acts as glue to bind soil particles together. Soil erodibility and crusting are both decreased by the aggregate stability's effect on pore space and tilth. Through increased saturated hydraulic conductivity, total porosity, and macro porosity, the roots and shoots of a plant affect the soil's physical qualities and the flow of water through it. Forage legumes are known as soil building crops because of their ability to link soil aggregates with organic matter after crop residues have decomposed (Holtham *et al.,* 2007).

Increased biological activity, seedling establishment, and root penetration can all result from better soil structure (Peypers *et al*., 2010). Because legume rhizo deposits are higher in substrate quality with a low carbon/nitrogen ratio, their adoption in cropping systems has a beneficial influence on the microbial activity in the soil (Nair and Ngouajio, 2012).

Compared to the overall microbial, bacterial, and actinomycetes activities in the soil are increased when alfalfa roots grasses release their substrate (Dhakal and Islam 2018; Kumar *et al.* 2018). Incorporating legumes in the crop rotation can be a great way to shake things up and boost the diversity of the microorganisms in your soil, which in turn improves biological pest management (Lupwayi *et al*., 2011).

Researchers have found that grass-legume combinations have higher total dry matter production compared to solitary grasses or cereals (Gulwa *et al.,* 2017) because legumes contribute nitrogen to the mixture. This means that increasing nitrogen fixation and fertilizer savings, boosting soil biology and biodiversity, and enhancing soil carbon sequestration through the cultivation of forage legumes can all be accomplished without compromising the long-term soil fertility base of the soil resources.

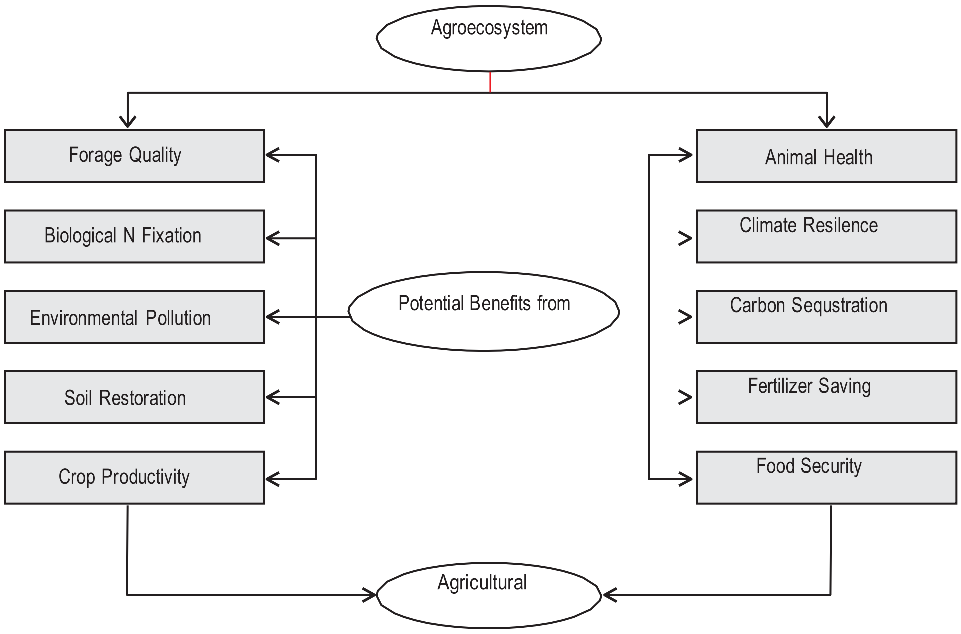


Figure 5.1: Flow diagram showing multiple agro-ecosystem services of forage legumes to agricultural production system

5.4 Inclusion of fodder crops in cropping systems for year-round fodder supply:

Less than 4.5% of India's total cultivated land area, or about 8.6 million hectares, can be used for growing fodder. However, increasing competition for the country's arable land makes expanding the acreage dedicated to fodder crops impractical. Increasing crop yield per unit land area and incorporating fodder crops into existing cropping systems may be the only method to meet the feed needs of animals. Consistently growing berseem, inter-planted with hybrid Napier in spring, and intercropping the inter row spaces of the grass with cowpea in summer after the final harvest of berseem on same piece of land in a calendar year ensures a steady supply of green fodder for dairy animals all year long. However, a large production of green nutritious feed and sustained soil fertility can be achieved by growing seasonal legume fodder crops, interplanted with perennial grasses (Hybrid Bajra Napier + Cowpea - Berseem). Accordingly, ensuring the production of grain, fodder, and other agricultural goods in a rainfed condition can be accomplished through the incorporation of forages into existing crop geometries. Higher and more consistent green fodder availability over a longer period of time is ensured by planting a mix of perennial and annual forage species that draws water and nutrients from multiple soil depths. Intercropping systems using sorghum and lima beans resulted in higher dry matter yields at varying sorghum-to-lima bean ratios. Intercropping pearl millet and cluster bean increased forage productivity and enhanced forage quality while maximizing the use of land and other resources (Ali *et al.*, 2016). It is also well established that forage and fodder crops are more productive in cereal-legume intercropping systems (Raj *et al.*, 2021). Reduced inorganic nitrogen application, increased soil carbon stocks, decreased runoff losses, greater drought resistance, and increased livelihood and profitability are just a few of the ways that forage production based on cereal-legume cropping systems lessens the world's carbon footprint (Kebede, 2020).

However, in the developed countries, cereal-legume based fodder cultivation has increased in the last two decades due to growing interests in conservation agriculture and growing feed demand for intensive dairy-based farming.

5.5 Legume Forages' Contribution to Food Safety:

As of 2050, the world's population is projected to reach over 9 billion, making food security a pressing issue. The demand for livestock products, such as milk, meat, and eggs, has increased dramatically as a result of urbanization (Magrini *et al.*, 2021). Consumption of meat and milk are predicted to increase by 2.8% and 3.3% annually in developing countries like India, respectively. In 2050, the demand for milk will be over 400 metric tons, and the demand for meat will be around 14 metric tons, while production in 2011 was around 122 metric tons and 6 metric tons, respectively. Food security in the face of climate change is one of humanity's greatest concerns, as the effects of climate change are widespread and severe. A climate-friendly approach and resilient agricultural practices under hazardous climate change need immediate consideration to ensure sustainable agricultural production (Zafar *et al.,* 2018; Ahmad *et al.*, 2019), but the problems associated with climate change are only beginning to emerge now. Cultivated forage and range legumes are an essential component for increasing the availability of high-quality animal protein, which in turn increases milk production and protects the health of animals. Around 40% of the global value in agricultural production comes from it, and it provides nutrition and food security to humans. This has a direct impact on the lives of about a billion people around the world, as well as on the diets and health of many more (Downing *et al*., 2017).

The demand for protein-rich and nutrient-dense food and meat is expected to rise dramatically due to significant progress in all developing nations. Alterations in the fatty acid profiles of livestock products like milk (Benbrook *et al.,* 2018) and meat (Fruet *et al.*, 2018) are a result of forage-based diets, especially in grass-legume combinations. Animals on a diet rich in fresh legumes and grass produce milk with higher levels of omega-3 fatty acids and conjugated linoleic acid (CLA), both of which are beneficial to human health by reducing the risk of cardiovascular disease. The perennial legume crop alfalfa (*Medicago sativa* L.) is currently the best global source of forage and feed. Alfalfa is utilized as a tonic because of the high quality proteins (60.5%), minerals, enzymes, vitamins, etc. it contains. Amylase, emulsion, coagulase perxidase, erepsin, lipase, invertase, and pectinase are only few of the alfalfa enzymes that have been documented. Cowpea [*Vigna unguiculata* (L.) Walp.] is a staple crop in sub-Saharan Africa (especially West Africa) and India, where the green leaves are used as nutritious livestock feed because they contain 29-43% protein on a dry weight basis. Because of their high protein and low fat content, cowpea plants are widely farmed throughout Asia for use as fodder, particularly in India (Samireddypalle *et al.*, 2017). Grain contains a variety of minerals and vitamins, including iron (33.6-79.5 mg/kg), zinc (22.1-58 mg/kg), phosphorus (3450-6750 mg/kg), calcium (310-1395 mg/kg), magnesium (1515-2500 mg/kg), and potassium (11,400-18,450 mg/kg) in addition to its protein content of up to 32% on a dry weight basis. In addition to being used as a grain, rice beans can also be used as fodder legume for animals (Khanal *et al*., 2009). Rice bean dry seeds are high in protein (18-26%) and relatively high in lysine (more than 6% of the protein) but low in sulphur-containing amino acids. They can be boiled and eaten with rice or used as a substitute for rice in stews and soups. Grass pea, also known as Lathyrus, has a high protein content (18–35%) in its seeds and 17% in its mature leaves, making it a promising candidate for the category of "functional food" (Llorent-Martnez *et al*., 2017). It can be used as feed and fodder for livestock, as well as a human food consumed whole or processed for split dal. Forage legumes have great potential to offer a balanced feed for cattle and to survive in a broad variety of climates, and this discussion has shown that their widespread use can help reduce global hunger and malnutrition.

5.6 Contribution of Legume Forage Crops on Climate Change Adaptation:

The concentration of atmospheric greenhouse gases (GHGs) like methane, carbon dioxide, and nitrous oxide has profoundly affected human societies and the natural environment, making agriculture extremely vulnerable to these changes (IPCC 2019). GHGs are responsible for warming the planet and contributing to extreme weather events. In order to guarantee long-term production, it is crucial to evaluate how climate variability affects agricultural productivity and devise adaptation techniques to deal with the risks posed by climate change. Domestic animals like temperatures between 10 and 30 degrees Celsius, and their feed consumption decreases by 3 to 5 percent for every additional degree over that. The productivity of animals would also be severely impacted by climate change scenarios due to drought and heat stress (van Wettere *et al.*, 2021). The development of adaptation and mitigation measures faces significant obstacles, chief among them the reduction of greenhouse gas emissions from agriculture and the production of additional food (Fujimori *et al*., 2021). In addition, legumes are highly efficient at reducing energy input needs and will lessen potentially dangerous greenhouse gas (GHG) emissions from agricultural land (Ray *et al.*, 2020). The cultivation of legumes, thanks to their biological nitrogen-fixing ability, can reduce the application of fertilizer N, which in turn reduces GHGs emissions (Sánchez-Navarro *et al.*, 2020; Sheoran *et al*., 2021), and is thus a good option towards climate change mitigation. The use of chemical fertilizers and the production of rice both contribute to the release of greenhouse gases into the atmosphere, making it imperative that both practices be reined in as soon as possible.

(Allen *et al.*, 2020). Current annual N_2O emissions are close to 17 million t (Schlesinger, 2009). As a result of increased nitrogen fertilizer use, it is predicted that worldwide N_2O emissions would increase to four times their current level by 2100 (Kahrl *et al.*, 2010). In grasslands, forage legumes can cut down on N_2O emissions because the reactive form of nitrogen in the soil is not easily available in the symbiotically fixed N found in legume nodules. However, carbon sequestration, bioenergy use, enhanced nitrogen management, and efficient fertilizer use are all examples of mitigating techniques that can help boost agricultural yield. The impact of modern research techniques on the development of forage crops can be seen in the creation of new varieties as well as the diversification of production systems, both of which are useful in preventing the spread of diseases and pests related to the altered climate. Because all of the carbon required for symbiotic N_2 fixation can be obtained from the atmosphere through photosynthesis, legumes are viewed as "greenhouse gas neutralizers" and offer many benefits. As a further technique for SOC/terrestrial sequestration, using forage legumes can help in net carbon sequestration, which aids in preserving soil organic carbon stocks and can provide a positive soil carbon budget. Scientists have shown that as temperatures rise, the nutritional value of grasses drops and ruminant cattle produce more greenhouse gases (CH_4 and methane) than usual (Lee *et al.*, 2017). Ingesting forage legumes can help reduce methane emissions from animals. Supplementing the diet with legumes has been shown to further lower CH_4 emissions by 15-30% per unit of meat or milk produced (Galloway *et al.*,2008).

This is because legumes contain fewer structural carbs and more condensed tannins than grass. The benefits of the legume in the diet in lowering methane emissions per unit gain were demonstrated by the methane emissions of Lucerna heifers fed a Leucaena leucocephala-stargrass mixture or grass only (Molina *et al.*, 2016). Because of the widespread availability of high-quality seed varieties, alfalfa, berseem, cowpea, and stylosanthes are among the most important contributors to forage production. Leguminous forages also provide a source of biological nitrogen fixation, which is useful for enriching soil, slowing the degradation of land, and mitigating the effects of climate change.

5.7 Conclusion:

Soil sustainability is increased, and the soil's health is improved with less chemical inputs thanks to forage legumes, which also benefit animals. Integrating forage legumes into crop production systems is crucial for long-term sustainability because of the many ways in which they boost crop-livestock production systems. Forage legumes increase soil quality, which benefits the ecosystem while also bolstering food and nutritional security. Therefore, long-term and multi-disciplinary approaches are required to evaluate the impact of forage legumes under altered climatic conditions on the production of high-quality animal feed, the preservation of natural resources, and, most importantly, the maintenance of food security.

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