REVIEW ARTICLE

Grain Legumes and Soil Health: Pathways to Sustainable Crop Production in Ethiopia: An Overview

Tamirat Wato[1]*, Sileshi Gemechu[1], Isreal Zewide[2], Alemu Andualem[1], Sate Sahle[3], Lasab Belachew[4], Gutema Urgi [4]

[1]Department of Plant Science, College of Agriculture and Natural Resource, Bonga University, Ethiopia
[2]Department of Horticulture, College of Agriculture, Mizan Tepi University, Ethiopia
[3]Department of Plant Sciences, College of Agricultura Sciences, Wachemo University, Ethiopia
[4]Department of Resource Utilization and Plant Protection, College of Resources and Environment Science, China Agricultural University, China

Corresponding Author: Tamirat Wato. Email: tamiratwato1@gmail.com
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Abstract
Grain legumes are vital components of sustainable farming systems, owing to their unique ability to improve soil fertility and support resilient crop production. Through biological nitrogen fixation, organic matter enrichment, soil structure improvement, nutrient cycling, pest and disease suppression, erosion control, stimulation of soil microbial activity, and carbon sequestration, legumes deliver multiple ecosystem services that reduce dependence on external inputs. In Ethiopia, soil fertility depletion and declining crop yields remain critical challenges, largely driven by unsustainable land management and limited crop diversification. This review examines the role of grain legumes in Ethiopian farming systems, highlighting their contributions to soil fertility, biodiversity, food security, income, and climate resilience, while stressing the need for improved breeding and management to enhance nitrogen fixation and adaptability. Integrating legumes into crop rotations and agroecosystems emerges as a promising pathway to restore soil health, conserve natural resources, and strengthen the long-term sustainability of Ethiopian agriculture. Finally, this review uniquely synthesizes evidence on Ethiopian grain legumes, framing them not just as food or cash crops but as key to soil health, food security, and climate resilience, while outlining context-specific pathways for their integration into smallholder farming systems.

Key words: Legumes; Biological N-fixation; Cropping systems; Soil health; Sustainable agriculture

Introduction

The legume family (Fabaceae), comprising an estimated 20,000 species, represents the third largest group of flowering plants worldwide (Shafique et al., 2014). Beyond their vital role in enhancing global food security, legumes are recognized as one of the most important and widely consumed sources of dietary protein (Popoola et al. 2014; Mashungwa et al., 2019). Their high protein levels, when combined with cereals, provide complementary amino acids, helping to address protein quality deficiencies commonly observed in smallholder farming systems. From an agronomic perspective, legumes are highly valued for their symbiotic associations with rhizobia and other nitrogen-fixing microbes. These interactions facilitate biological nitrogen fixation (BNF), converting atmospheric nitrogen into plant-available ammonia. This process improves soil nitrogen status, decreases dependence on chemical fertilizers, and contributes to long-term soil fertility (Bhatt et al., 2019; Kebede, 2021). In Ethiopia, practices such as legume-cereal rotations, intercropping, the use of legumes as green manure, and improved fallows have been widely reported to enhance soil health, increase nutrient cycling, suppress pests, and improve cereal yields (Kebede, 2021; Kebede et al., 2020).

Legumes are grown using a variety of cropping techniques, such as rotation, intercropping, and solitary cropping. Peterson et al. (2010) identified legumes and legume-based agricultural systems as viable remedies for food and nutrition insecurity in a range of populations. Similarly, this authors explained as legumes and crops derived from them are promoted for smallholder farmers in most developing nations. Smallholder farmers in Asia, Africa, and Latin America have long engaged in intercropping, which is now becoming more popular due to its ability to preserve space and yield large yields with little input (Yu et al., 2015). For instance, because pigeon peas can withstand drought, farmers in drought-prone areas have long utilized them as an intercrop with cereals (Semahegn, 2022). Nonetheless, due to land constraints, the majority of small-scale farmers cultivate legumes as intercrops for basic cereals, especially maize. As intercrops, legumes and cereal crops have a symbiotic biological commensalism that benefits farmers. Cereal crops develop and yield more when legumes fix N and add more organic matter to the soil (Yuvaraj et al., 2020). When intercropping, farmers should take into account elements including suitable species, planting time, physiological traits of the intercrop, growth patterns, canopy, root architecture, and water and fertilizer requirements (Semahegn, 2022). It is not recommended for farmers to grow legumes as single crops since they can lead to a decrease in soil fertility and a rise in pest and disease problems.

Crop rotation methods, which cultivate a variety of crop species consecutively on the same plot of land, have been known to employ legumes. Crop rotation has repeatedly been demonstrated to lower soil erosion, improve water consumption efficiency, and sustain high yields (Shah et al., 2021; Yang et al., 2023). For instance, a two-crop rotation uses maize (*Zea mays*) and soybean (*Glycine max*) or maize and alfalfa (*Medicago sativa*) in alternate years to provide complementary inorganic nitrogen in the soil for succeeding crops. Mixtures of legumes, grains, or tubers can also be created using legumes. This farming system benefits from combining growth elements such as soil nutrients, light, and water, fewer pests and diseases, and reduced soil erosion. This cropping strategy increased yield stability and biomass production. Legume production has become more of a focus due to growing awareness and concern about the security of food and nutrition for humans and animals as well as declining environmental health, particularly in smallholder farms (ICRISAT (International Crops Research Institute for Semi-Arid Tropics), 2016). Legumes are an essential source of food and nutrition, and using them in a production system can lower pest and disease levels, stop soil erosion, and boost crop yields (FAO, 2016; Neda, 2020). In order to encourage pulse farming, the Food and Agriculture Organization (FAO) of the United Nations (UN) proclaimed 2016 to be the International Year of Pulses (FAO, 2016).

Despite their agronomic and environmental benefits, legume adoption and productivity in Ethiopia remain below potential due to technical, economic, and institutional constraints. Yields are low, mainly because of limited use of improved varieties, poor agronomic practices, and restricted access to quality seeds and inputs (Atnaf et al., 2015). High input costs, weak seed systems, and insufficient extension support further hinder adoption (Ferede et al., 2014; Kebede et al., 2020). Farmers also face poor market infrastructure, unstable prices, and limited linkages, which discourage investment in legume production (Asfaw et al., 2010). Environmental stresses such as soil acidity, drought, and climate change, combined with pests and diseases like faba bean gall, further reduce yields (Atnaf et al., 2015; Kassa et al., 2024). Moreover, legumes are often regarded as “secondary crops” compared to cereals, resulting in limited research, policy attention, and investment (Ferede et al., 2014). In general, legume production in Ethiopia is constrained by interlinked biophysical, economic, and institutional factors. Addressing these challenges is essential for harnessing the full potential of legumes to improve soil fertility, enhance food security, and promote sustainable crop production. Accordingly, this review aims to highlight the significance of legumes in advancing sustainable agriculture and soil health in Ethiopia.

The concepts of legume crops

Grain legumes are members of the angiosperm family Fabaceae (Leguminosae). Recognized for their distinctive floral structure, compound leaves, and pod-like fruits, legumes are a botanically varied and economically significant group of plants. Beans, peas, lentils, and chickpeas are examples of legume grain crops that are well-known for their capacity to fix atmospheric nitrogen through rhizobial bacterial symbiosis. Furthermore, a crucial ecological trait promoting soil fertility and sustainable agriculture is their capacity to establish symbiotic partnerships with bacteria that fix nitrogen (Doré et al., 2011). They are thought to be abundant in high-quality proteins and have a big impact on people's diets, nutrition, and general health all over the world (Popoola et al., 2019). These are the edible seeds of plants belonging to the legume family, and they all develop into pods. They are gathered, allowed to reach maturity, dried, refrigerated for extended periods of time, and then sold in a dry state for use as food, feed, or in the creation of other goods (Getachew, 2019). Legumes are therefore significant for a variety of reasons, such as economic advantages, nutrition, agricultural, and environmental sustainability.

Opportunities in Adopting Legume Production in Ethiopia

Despite the challenges, Ethiopia has significant opportunities to enhance legume production and unlock its full potential. Ethiopia is endowed with a diverse range of agro-ecologies, making it suitable for cultivating a wide variety of legume species. This geographical advantage allows for the production of different legumes, including faba beans, chickpeas, lentils, and haricot beans, which can be adapted to specific regions and climatic conditions (Getachew, 2019). There is a high and increasing demand for legumes, both domestically and internationally, driven by a growing population and urbanization. Legumes are a staple in the Ethiopian diet and a cost-effective source of protein, making them crucial for household food security (Getachew, 2019). Legumes have the unique ability to fix atmospheric nitrogen in the soil, which improves soil fertility and reduces the need for synthetic fertilizers. This makes them a critical component of sustainable and climate-smart agricultural systems, especially when used in crop rotation. Increased legume production can create opportunities for local value-added processing, stimulate domestic demand, and provide off-farm employment and income sources for smallholder farmers (Kebede, 2020). Legumes are also a major export commodity, providing a source of foreign exchange for the country. Legumes provide high-quality feed for livestock, which can enhance animal nutrition and productivity. Integrating legumes into mixed crop-livestock systems can improve nutrient cycling and overall farm productivity. Continued agricultural research and the development of new, improved legume varieties that are drought-tolerant and disease-resistant offer a significant opportunity to increase productivity. This is complemented by initiatives and projects aimed at deploying these technologies to farmers (ICARDA, 2022).

Ethiopia has considerable opportunities to enhance legume production due to its diverse agro-ecologies, which support a wide range of species such as faba beans, chickpeas, lentils, and haricot beans. Rising domestic and international demand, driven by population growth and urbanization, underscores their importance as a staple food and affordable protein source. Beyond nutrition, legumes improve soil fertility through nitrogen fixation, reduce fertilizer needs, and play a vital role in sustainable, climate-smart agriculture. Expanding production can also boost exports, create value-added processing opportunities, generate off-farm employment, and strengthen mixed crop-livestock systems by providing high-quality feed. Furthermore, ongoing research and the development of improved, stress-tolerant varieties offer strong potential to increase productivity and resilience.

Empirical Evidence on legume production

Ethiopia is both a major producer and an important trader of pulses, and national policy recognizes legumes as a strategic lever for soil restoration and sustainable intensification. Pulses account for large national production volumes and figure among exported commodities, while government technical guidance on Integrated Soil Fertility Management (ISFM) explicitly promotes legume integration to address widespread soil fertility decline and low crop yields (ITD, 2022/23; Manzoor et al., 2025). National ISFM manuals and field guides have been used in extension and restoration programs to mainstream legumes as part of multi-pronged soil health packages (ITD, 2022/23).

Field experiments and on-farm research across Ethiopian agroecologies provide strong, locally relevant evidence that legume-to-cereal rotations deliver measurable agronomic and soil-fertility benefits. A Mesfin et al. (2023) field study in northern Ethiopia reported that preceding wheat with faba bean, field pea and lentil increased subsequent wheat grain yield by ~1.1–2.2 $t \cdot ha^{-1}$ (2196, 1616, 1254 and 1065 $kg \cdot ha^{-1}$ for faba bean, “dekeko”, field pea and lentil respectively) and substantially increased N uptake relative to continuous wheat - a clear, locally measured “rotation dividend” for smallholder systems. Similar rotation benefits (yield gains of ~5–7% relative to continuous wheat) have been reported in the central highlands and southern Ethiopian trials, demonstrating that the legume yield dividend is robust across contrasting highland contexts (Mesfin et al., 2023).

Beyond immediate yield effects, Ethiopian studies highlight genotypic variation and management interactions that determine how much soil benefit a legume will deliver. Recent work on faba bean shows considerable genotypic variation in symbiotic N_2-fixation traits and differential responses to phosphorus supply and rhizobial inoculation-implying that breeding and targeted management (P fertilization, inoculants) can enhance the BNF contribution of legumes under Ethiopian soil conditions. Trials examining phosphorus responses, inoculation and seed/variety choice have recorded large differences in biomass, grain yield and estimated N contributions, indicating clear avenues for improving legume performance through both breeding and adaptive agronomy (Abu et al., 2024). Programmatic and policy enablers are beginning to align. CGIAR and national partners (e.g., ICRISAT activity in Ethiopia) have invested in improved legume germplasm, seed system strengthening, and seed policy support; these actions increase farmer access to improved varieties that better express BNF and yield potential. At the same time, major climate and landscape restoration investments (including Climate Investment Funds / World Bank–backed programs) are channeling funds into land restoration, soil health regeneration and sustainable farming, creating opportunities to scale legume-based interventions at landscape scale (Jessop, 2024).

Critical constraints remain and shape realistic expectations for scaling legume benefits in Ethiopia. Seed system gaps, weak extension reach for pulses, constraints in access to inoculants and phosphorus, and heterogeneity in farmer objectives limit adoption and the full expression of legume ecosystem services. National ISFM manuals and seed policy briefs emphasize these gaps and recommend integrated interventions-combining breeder and agronomy work, seed system reform, tailored extension, and incentives that recognize both food-security and soil-restoration benefits (ICRISAT, 2022-2024). Table 1 summarize the empirical evidence underscores that Ethiopia has significant untapped potential to enhance legume productivity. Closing the yield gap requires integrated interventions that strengthen seed systems, expand access to inputs and services, and promote market linkages. Such measures, coupled with location-specific research and gender-responsive extension, are essential for realizing the dual benefits of improved household welfare and sustainable agricultural intensification.

Table 1: The summary of empirical evidences on legume production and productivity from Ethiopia

No	References	Location / context	Experiment / design	Main result (headline)
1	Mesfin S., (2023)	Northern Ethiopia (trial)	Field experiment: legume (faba bean, field pea, lentil) → wheat rotations vs continuous wheat	Wheat yield increased by 1.06–2.20 $t{\cdot}ha^{-1}$ after legumes; large increases in N uptake.
2	Mekonnen and Endrias (2023)	Central highlands, Southern Ethiopia	Crop rotation trial (faba bean/field pea → wheat vs continuous wheat)	Wheat yield +5–7% after faba bean/field pea relative to continuous wheat.
3	Abu et al., (2024)	Multi-site faba bean trials (Ethiopian contexts)	Genotypic evaluation for symbiotic N_2 fixation under contrasting P regimes	Significant genotypic variation in BNF traits; responses to P indicate breeding + P management improve fixation.
4	Jithesh et al., 2024	Review including Ethiopia-relevant studies	Synthesis of BNF enhancement strategies (inoculation, fertilization)	Rhizobial inoculation and P optimization commonly increase BNF and yield-actionable in Ethiopian settings.
5	Negasa and Dobocha (2025).	On-station Faba bean P response trial, (Ethiopia)	P fertilizer gradients + management	40 kg $P{\cdot}ha^{-1}$ increased biomass and seed yield substantially (headline yield responses reported).
6	MoA (2020)	National / extension context	Technical manual and field guide promoting ISFM	Legumes recommended as ISFM component to restore soil fertility and improve smallholder resilience.
7	ICRISAT / CGIAR seed-system reports (2022–2024).	Programmatic (seed systems)	Variety dissemination, seed system strengthening	Improved pulses varieties and seed system activities show progress in supply and adoption enablers.
8	Jessop (20224)	Climate Investment Funds or National investment / restoration program	CIF and partners backing large restoration programs	$37–500M funding endorsement for land restoration, soil health and sustainable farming-political and finance window to scale legume interventions.

Importance of legumes

The foundation of a balanced diet and sustainable agriculture is legume crops. They are a priceless tool for advancing environmental sustainability, food security, and economic stability due to their beneficial effects on soil health and the ecosystem. Growing more legumes is essential to replenishing nutrient-deficient soils and providing people and animals with the necessary protein, minerals, and vitamins. Globally, legumes can help smallholder farmers make a better living (Yuvaraj et al., 2020). Furthermore, given of their market demand and cheaper input costs for pesticides and fertilizers, they can be very profitable crops for farmers. Thus, healthier populations and a more sustainable world can result from increasing the amount of legumes in diets and agricultural systems.

Legumes in human nutrition

With a protein level ranging from 17 to 40%, grain legumes (such as pigeon pea, chickpea, soybean, or mung bean) are a true source of protein. Farmers and their families can enhance their diets and achieve protein stability by consuming grains together with cereals. Legumes seeds are a rich source of vital vitamins and minerals, including folic acid and Vitamin B. They also include significant amounts of minerals, such as calcium, zinc, and iron, and nutritional vitamins (Yuvaraj et al., 2020). Legumes also contribute significantly to food security by offering a dependable source of protein and other nutrients, especially in poorer nations where access to animal protein may be restricted. All things considered, adding a range of legumes to the diet can greatly improve its nutritional value and promote general health. As key parts of a balanced diet, they supply vital nutrients, help avoid chronic diseases, and provide a sustainable source of protein.

Legumes for animal nutrition

The productivity of healthy animals was significantly boosted by cereal crop wastes supplemented with feed legumes. For instance, it has been noted that adding protected pulse grains to poultry feed boosted egg output. Legume flora leftovers can improve the digestibility and quality of cereal crop residues when added to cattle feed. For instance, adding leguminous flora will increase animal nutrition because maize residues often contain low levels of proteins and large levels of carbohydrates (Yuvaraj et al., 2020). Therefore, incorporating fodder crops based on legumes into livestock systems can support sustainable farming methods. Additionally, using legume cover crops and rotational grazing can enhance soil health, give farmers more revenue streams, and lower greenhouse gas emissions from livestock operations.

Legumes for crop and soil improvement

Plants need mineral nutrients, the most important of which is nitrogen, to produce the maximum amount. Because exhausted soils frequently have low nitrogen contents, farmers typically use inorganic fertilizers. Farmers struggle to achieve enough yields, though, as fertilizer costs rise. Legumes can be added to cropping systems to help with this issue. Leguminous plants are closely associated with Rhizobium, a type of bacterium that fixes nitrogen. Thus, legumes offer an incredibly affordable way to alter soil nitrogen, enhance soil fertility, and increase crop yields in the future by naturally fixing nitrogen levels in the soil (Yuvaraj et al., 2020).

Role of grain legumes to sustainable crop production

Due to the existing severe pressure on water and land, the fast expanding population is having an impact on food and nutrition security. Degradation due to global warming, pollution, and loss of soil fertility are some of the negative effects on soil health (Swaroop and Lal, 2018). When incorporated into crop rotations and intercropping schemes, legumes can serve as substitutes to promote soil stability under such circumstances. Legumes fix atmospheric N_2 in symbiosis with rhizobial bacteria, which makes them a valuable component of integrated soil fertility management. Moreover, these crops supply inputs of organic matter that enhance crop yields and have a good impact on the chemical, physical, and biological characteristics of the soil (Bashir et al., 2021).

Legumes increase productivity as intercrops on maize farms while maintaining nutrient availability, claim Choudhary and Choudhury (2018). As part of a grain legume maize-based cropping system, Chimonyo et al. (2019) observed an improvement in soil fertility and water-holding capacity, which they linked to a rise in maize productivity. This makes sense given that systems of legume cropping increase soil fertility, improve soil health, and increase soil resistance to several types of erosion (Kintl et al., 2015). By boosting beneficial soil microorganisms and increasing soil biodiversity, the use of legumes in farming systems improves ecosystems (Meena et al., 2014). These crops ensure protection from pests and diseases, improve nearby plants, and lessen soil erosion through mineralization (Lal, 2013). According to Sugiyama and Yazaki (2012), legumes have large root systems and emit exudates that greatly enhance the dynamics, structure, and quality of the soil's nutrients. These legumes also help to recycle nutrients, such as nitrogen, phosphorus, and carbon. Many legumes, such as lupin (*Lupinus angustifolius* L.), vetches (*Vicia sativa* L.), and velvet bean (*Mucuna pruriens* Bak.), fenugreek (*Trigonella foenum-graecum* L.), clover (*Trifolium* sp.), showy rattlebox *(Crotalaria spectabilis)*, and water bean (*Sesbania rostrata*) have also been used as green manure (Swaroop and Lal, 2018). These crops provide good sources of nutrients for plants by increasing soil organic matter and nutrient availability when applied as green manure. Consequently, adding these crops to a rotational system would increase the amount of nitrogen available for plantings that come after them (Hauggaard-Nielsen and Jensen, 2005).

It is difficult to achieve sustainable productivity, especially in underdeveloped countries. The improper use of agrochemicals has made matters worse by negatively affecting the health of the soil. Shahid et al. (2020) claim that improper and needless application of fungicides to prevent soil-borne illnesses and boost crop yields negatively impacts soil fertility, microbial composition, and grain yield. Therefore, crop rotation based on legumes is a more effective way to preserve the ecosystem. Crop rotation greatly enhances the microbiological state of the soil because legume leftovers provide a food source for soil biota, which enhances productivity, nutrient mineralization, and soil functions. Because they address the issues associated with low productivity, legumes play a significant impact in increasing productivity (Shahid et al., 2020).

Grain legume production systems

Systems for producing grains and legumes are essential to sustainable agriculture and offer advantages in terms of economy, nutrition, and ecology. To maximize crop productivity and sustainability, effective management techniques are essential. These practices include crop selection, soil management, and integrated pest and weed control, and efficient water usage. Farmers may contribute to food security, environmental sustainability, and improved soil health by growing legumes in a variety of cropping systems. Depending on the climatic and edaphic circumstances as well as the planned end use, grain legumes are generated in a variety of methods, including dry grain, green feed, arable silage, and green manure (Watson et al., 2017). Various species of legumes are grown: pea (*Pisum sativum* L.), lupins (*Lupinus* spp.), faba bean (*Vicia faba* L.), chickpea (*Cicer arietinum* L.), lentil (*Lens culinaris* Medik.), common bean (*Phaseolus vulgaris* L.) and soybean (*Glycine max* (L.) Merr.) (Vanlauwe et al., 2019). Legumes can be grown as standalone crops or as intercrops with cereals such as maize.

Intercropping

Growing two or more crops from different families and species is known as intercropping. The main crops are the only ones that are important, and the other crops are grown as secondary crops that enhance the soil and fix nitrogen. Numerous legumes offer great chances for resource efficiency by intercropping with early maturing crops. According to Meena et al. (2014), intercropping encourages species interactions, boosts biological variety, and aids farmers in adjusting to climatic irregularities. The primary crop, the variety of legumes available, the maturity period, the height of growth, and the farmers' preferences all influence the choice of legume intercrop. Planting arrangement and spacing are determined by species, the potential for automation, the growing status of intercrops and primary crops, current climate, and soil fertility. Comparing legume-based intercropping systems to monocropping systems, higher production is obtained from the same field, and natural resource efficiency is enhanced (Inal et al., 2007). Fustec et al. (2010) claim that leguminous crops outperform monoculture farming systems because they enhance soil functions through biological nitrogen-fixing. Legume-based intercropping is a sustainable agricultural production technique that is environmentally friendly and requires little in the way of inorganic nitrogen (Ashoka et al., 2017). This demonstrates that intercropping is a sustainable farming method that boosts crop yield, strengthens the health of the soil, and encourages ecological balance. Thus, intercropping improves biodiversity, controls weeds, and lessens the burden of pests and diseases by diversifying crop production. By supplying a variety of revenue streams and stabilizing yields, it helps farmers monetarily. By decreasing the demand for chemical inputs and increasing the resilience to climate change, intercropping promotes environmental sustainability. All things considered, intercropping is an essential technique for developing sustainable agricultural systems.

Crop rotation

Crop rotation, as opposed to monoculture which is the continuous growth of one crop on the same land, is a system in which various crop kinds are cultivated on the same land in recurrent and specific sequences (Zhao et al., 2020). Crop rotation can increase productivity and sustainability in crop production systems where legumes are included in maize/sorghum production systems (Keeler et al., 2009). Grain legumes are an alternate crop that can be grown in rotation farming to promote soil recovery and production diversification. This lowers the prevalence of pests and illnesses while also increasing soil fertility and biodiversity. To increase soil sustainability and productivity, grain legumes are planted as part of crop rotation (Watson et al., 2017). Crop rotation increases biological variety and decreases dependency on chemical fertilizers, which increases crop yields and the sustainability of production systems. It also enhances soil permeability, microbial activity, water-holding capacity, and organic matter. According to Knight (2012), the frequency at which legumes are generated has an impact on soil microbial activity and nitrogen fixation. However, Brouwer (2006) claims that there is a trend in agricultural production systems toward specialization, which has led to a progressive loss of diversity. Therefore, biological processes like using pesticides in place of ecological pest control or biological nitrogen fixation (BNF) in place of mineral fertilizers are affected (Zander et al., 2021). It is recommended that farmers cultivate a variety of crop species with varying life cycles to optimize pest and disease control and concurrently leverage nutrient availability via crop rotation (Cook, 2013). Crop yield and sustainability can benefit greatly from crop rotation, an established agricultural technique. It improves the health of the soil, breaks down the cycles of disease and pests, controls weed growth, and supports environmental sustainability. Crop rotation is one way that farmers can create more resilient and sustainable agricultural systems that will guarantee ecological balance and long-term productivity.

Mixed cropping

Mixed cropping, which involves growing legumes, cereals, or tuber crops, is a typical approach in marginal agro-ecological areas. This cropping method serves several purposes, including the complementary utilization of growth elements such as soil nutrients, light, and water (Doré et al., 2011). This approach also decreases pests, illnesses, and soil erosion while increasing biomass and overall yields (Staniak et al., 2014). Furthermore, the combinations are easily adaptable to account for variables such as the timing of the rainy season or soil fertility levels in different areas (Weltzien et al., 2017). Legume cereal mixes require less nitrogen fertilizer than cereal crops do. As a result, there was an increase in the protein content of cereal seeds. Zarea et al. (2008), while working on the effects of forage legumes mixed crops on biomass production and bacterial community structure, found that mixed cropping enhanced the number of bacteria, free-living N_2-fixing bacteria, and Azotobacter in the rhizosphere. Studies on cropping mixtures of yellow lupine with wheat and oats have indicated the competitive potential of a single legume compared to a single cereal plant (Staniak et al., 2014). Mixtures of legumes and cereals create allelopathic conditions that may significantly influence the plant stand and yield output.

Monocropping

Monocropping is the practice of planting only one crop on the same plot of land each year. This approach is prohibited since alternate agricultural systems based on legumes, rather than monoculture production, have superior economic and environmental outcomes and reduce the prevalence of pests, illnesses, and weeds (Nigli et al., 2008; Doré et al., 2011; Kebede, 2020).

Table 2: Summary on seed yields (kg ha^{-1}) of castor as influenced by sole cropping, alley cropping, green leaf manures, and nitrogen levels

Treatment	N_0	N40	N80	Mean
Sole cropping No green leaf manuring	263	470	570	434
Leucaena green leaf manuring	349	618	679	548
Albizia green leaf manuring	335	585	666	528
Dalbergia green leaf manuring	347	529	653	510
Mean	323	551	642	505
Alley cropping No green leaf manuring	348	672	745	588
Leucaena green leaf manuring	500	760	851	704
Albizia green leaf manuring	428	753	833	671
Dalbergia green leaf manuring	425	756	831	671
Mean	425	735	815	659
LSD (0.05) Cropping systems	8.2			
Nutrient	8.78			
Interaction	12.57			

Source: Ghost et al. (2007) cited by Kebede (2021)

Similarly, growing some legume species as monocultures continuously continuously may result in nitrate leaching (Vasconcelos et al., 2020), while others may result in high N_2O emissions. Similarly, Ghost et al. (2007) cited by Kebede (2021) reported that the sustained practice of alley cropping with nitrogen-fixing leguminous trees serves as an effective approach to harness biological nitrogen fixation (BNF). The effects of sole cropping, alley cropping systems, application of green leaf manures, and varying nitrogen levels on castor seed yield are presented in Table 2. Senbayram et al. (2016) found that when legumes were grown in monocultures, they produced higher cumulative N_2O emissions than fertilized wheat. Due to the numerous constraints of employing legumes as monocultures, farmers are urged to grow legumes as intercrops, rotational crops, or mixed crops.

Contribution of legume to soil health

Legumes in soil quality

Legumes improve soil quality by fixing nitrogen, adding organic matter, improving soil structure, controlling erosion, suppressing weeds, increasing microbial activity, cycling nutrients, and managing soil moisture. Legumes have several advantages, including increasing soil natural matter, enhancing soil porosity, recycling nutrients, improving soil structure, decreasing soil pH, diversifying microscopic lives in the soil, and reducing disease buildup and weed problems in grass-type crops (Stagnari et al., 2017). Integrating legumes into agricultural systems, whether through crop rotations, cover cropping, or intercropping, can result in more sustainable and productive soils, enhancing the overall health of agricultural ecosystems.

Soil natural rely

Since legumes can fix atmospheric nitrogen, improve soil fertility, limit erosion, sequester carbon, manage weeds and pests, and effectively manage water, they are essential for natural soil replenishment. Because they contain a lot of protein, legumes are rich in nitrogen. Legume-derived nitrogen accelerates residue decomposition by balancing the soil C:N ratio (Stagnari et al., 2017). Table 3 presents the nutrient composition and carbon-to-nitrogen (C:N) ratios of the above-ground biomass of key legume green manure crops. These measurements highlight each species' capacity to enrich soil fertility and influence organic matter turnover. Variations in nutrient levels demonstrate differences in nitrogen fixation, biomass production, and nutrient recycling potential, while the C:N ratios indicate how quickly residues decompose and release nutrients. This knowledge is essential for choosing suitable legume species that can improve soil quality, benefit succeeding crops, and strengthen sustainable agricultural systems. According to Ghosh et al. (2007) cited in Kebede, (2021), intercropping with *Leucaena leucocephala* led to yield reductions of approximately 38% in maize, 34% in black gram, and 29% in cluster bean compared to their respective sole cropping systems. As a result, the decomposition of leftover legumes enriches the soil with organic materials. Improved soil structure, water-holding ability, and cation exchange capacity, all essential for nutrient availability and retention come from higher levels of organic matter content. Therefore, increasing the productivity and sustainability of farming systems may result from including legumes into agricultural methods through crop rotation, cover crops, and green manuring. Farmers can increase their production and long-term health while lowering their need for chemical fertilizers by taking advantage of the natural advantages of legumes.

Soil porosity

As a result, the soil becomes richer in organic matter as leftovers from legumes break down. A higher level of organic matter enhances the soil's ability to store water, exchange cations, and maintain nutrients, all of which are critical for nutrient availability and retention. Cover cropping, green manuring, and crop rotation are ways to include legumes in agricultural methods that may result in more productive and sustainable farming systems. Farmers may increase their productivity and long-term health by utilizing the natural benefits of legumes and lowering their need for chemical fertilizers. Therefore, improving the structure and health of the soil through the use of legumes as cover crops, intercropping systems, or crop rotations can promote a more fruitful and sustainable agricultural system.

Table 3. Nutrient concentrations and carbon-to-nitrogen (C:N) ratios in the above-ground biomass of selected green manure crops (Source: Ghosh et al., 2007 cited in Kebede, 2021)

	Total Nutrient concentration (% dry weight)						
Green manure crops	N	P	K	S	Ca	Mg	C: N ratio
Sesbania (Sesbania aculeata)	2.62	0.32	1.48	0.19	1.40	1.62	16.4
Sunnhemp (Crotalaria juncea)	2.86	0.34	–	–	–	–	16.1
Cowpea (Vigna unguiculata)	2.69	0.28	2.26	0.28	1.50	1.73	17.1
Cluster bean (C. tetragonoloba)	2.80	–	–	–	–	–	17.3
Mung bean (Vigna radiata)	2.21	–	–	–	–	–	16.1
Subabul (L. leucocephala)	3.15	0.20	1.73	–	1.88	0.41	12.7
Gliricidia (Gliricidia maculata)	3.49	0.22	2.44	–	1.89	0.43	10.42

Recycle nutrients

The recycling of nutrients are facilitated by legumes in both natural and farmed environments. Legumes indirectly contribute to overall nutrient cycling mechanisms that can improve vitamin and other micronutrient availability and recycling, even if direct vitamin recycling in the soil-plant system is not as important as it is for minerals like phosphorus or nitrogen. Although legumes do not directly recycle vitamins in the same manner as they fix nitrogen, they do play a major role in enhancing the entire nutrient cycling process by improving soil health, structure, and fertility. Legumes improve soil structure, add organic matter, encourage microbial activity, and increase nutrient availability, all of which help recycle and make vitamins and other vital nutrients more available to plants in the soil. Deeply rooted crops can recycle nutrients from the soil profile because perennial and biennial legumes have deep roots. As a result, fertilizer is used more sustainably, and less nutrients, especially nitrate nitrogen are lost as a result of leaching beneath the roots of crops with shorter roots later in the cycle (Figure 1). Increasing soil sustainability is one of the advantages of legume crops (Stagnari et al., 2017). Therefore, incorporating legumes into crop rotations, cover crops, and green manuring can help to create an environment that is more nutrient-rich and sustainable.

Improve soil structure

Typically, legumes have large, deep root systems that aid in improving the structure and porosity of the soil by breaking up compacted soil. In succeeding crops, this improved water infiltration and root penetration. The rise in more stable soil aggregates was blamed for these advancements. The protein called glomalin functions as a "glue" to hold soil particles together into stable aggregates. It does this symbiotically along the roots of legumes and other plants. According to Stagirari et al. (2017), this aggregate stability decreases crusting and soil erodibility by increasing pore space and tilth. Because of their deep, fibrous root systems, organic matter addition, improved soil porosity and aeration, improved water infiltration and retention, erosion control, microbial activity stimulation, and decreased soil compaction, they thus play a crucial role in improving the soil structure. Legumes can therefore be incorporated into crop rotations, cover crops, and green manuring techniques to improve soil health, boost production, and guarantee the sustainability of agricultural systems.

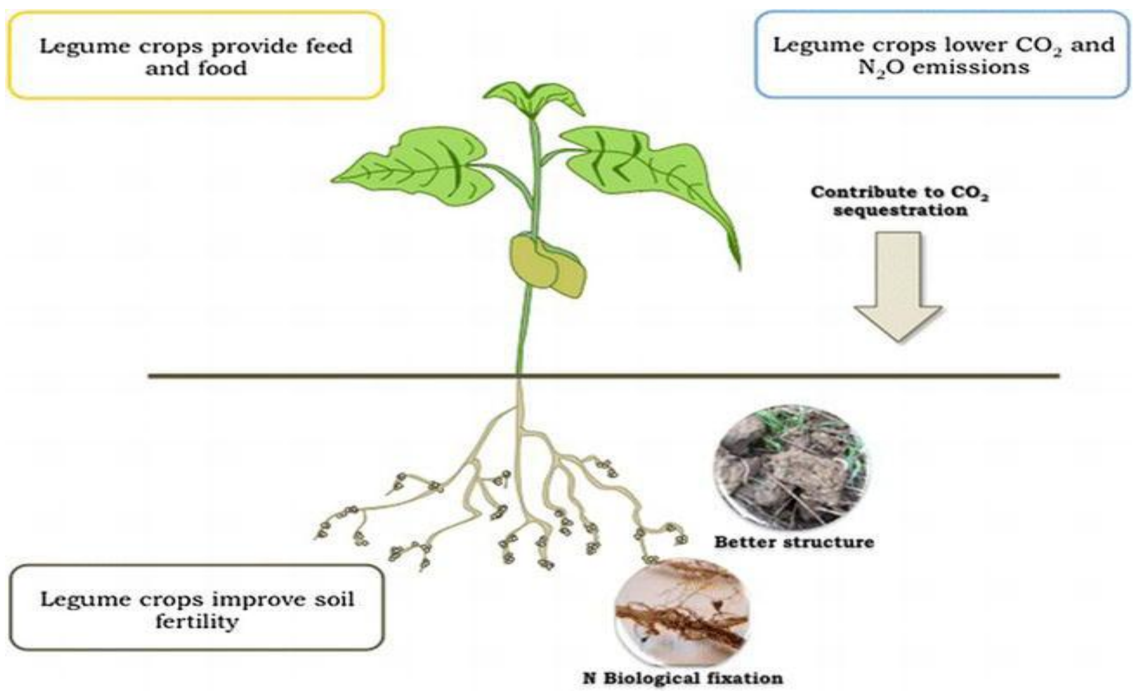

Figure 1: Role of legumes crops in improving soil fertility (Source: Stagnari et al., 2017 cited by Yuvaraj et al., 2020)

Lower soil pH

Though they usually do not significantly lower soil pH on their own, legumes can affect soil pH through a number of methods. Their interactions with soil processes and microbial activity are often linked to their impacts on soil pH. Legumes do not directly lower soil pH, but their biological activities and interactions with soil microbes can create environments that do. This involves the generation of organic acids from root exudates and the breakdown of organic matter, the release of H^+ ions during nitrogen fixation and nutrient intake, and increased microbial activity that results in the synthesis of CO_2 and carbonic acid. Soil pH is lowered by inoculated, nodulated legumes because they obtain nitrogen from the air as diatomic N instead of the soil as nitrate. Alfalfa and soybeans decreased the pH of clay loam soil in greenhouse experiments by one unit. In soils with a pH above the limit for the best crop growth and development, legumes can lower pH and improve plant-soil-microbial activity (Stagnari et al., 2017). Legumes can gradually affect soil pH through crop rotation and soil management techniques, improving overall soil health and nutrient availability.

Soil fertility improvement

Grain legumes are vital crops in various cropping systems because they fix atmospheric nitrogen in the soil and increase phosphorus turnover by biological processes. Legumes aid in the cycle of other vital elements including potassium and phosphorus. Additionally, by nutrient recycling that is, through releasing organic acids that help solubilize phosphorus so that plants may access it more readily they increase soil fertility. Grain legumes cover over 190 million hectares worldwide, and they add 5–7 million tons of nitrogen to soils annually (Vidigal et al., 2019). Because of their ability to fix nitrogen, legumes can save up to 60% of the fertilizer needed for cereals the following season. Intercropping and rotating between legumes and cereals might help preserve soil health and minimize the need for fertilizer, as the cultivation of cereals leads to a greater depletion of soil nutrients (Yirga et al., 2010). Additionally, they increase soil fertility by promoting microbial activity, which is made possible by the presence of legumes in the soil. Thus, the breakdown of organic matter, the cycling of nutrients, and the overall fertility of the soil are all improved by active soil microbial communities.

Contribution of legume residues to soil sustainability

Due to their relatively high nitrogen content, legume residues can provide a source of mineral nitrogen for crops that come after them (Kebede, 2020). According to Louarn et al. (2015), nutrients obtained from broken-down sections of legume plants make up a substantial portion of the nutrients transferred below ground. According to Moura et al. (2015), both live and dead soil surface cover legumes increase soil root capacity and decrease soil moisture loss and evapotranspiration rate. Sangare et al. (2016) state that using residues from legume crops is an alternate strategy for raising soil fertility. Legume residues do, however, contribute to a soil N pool that releases nitrogen over time rather than acting as a quick source of nitrogen for plants (Formowitz et al., 2009). Research has indicated that the incorporation of organic wastes into soil leads to higher crop yields (Shafi et al., 2014). The impacts of legume trees on soil im provement were investigated by Moura et al. (2015). Treatments with high biomass had increased carbon stocks in the litter and total organic carbon. Moura et al. (2015) state that to keep the balance between carbon inputs and rapid decomposition rates, leftovers must be added continuously. To boost their effectiveness, mineral fertilizers and organic residues can be combined, and a more prudent strategy that combines mineral fertilizers with soil organic additions such legumes is being advocated (Moura et al., 2015). More cover crops made of legumes have so been encouraged to be used as green manures. However, the benefits of legumes for soil fertility are contingent upon their legume-cereal ratio, the length of time that legume biomass is produced, and the management of residues. To reduce the amount of nutrients added to the soil, edible legumes, for example, are typically collected and their leaves eaten as vegetables or fodder. According to estimates, the nitrogen benefit of adding a grain legume to a rotation is between 0 and 90 kg N ha^{-1} for soybeans with a short or medium growth period and usually higher for legumes with a longer growth period, like pigeon peas, which grow for about 180 days (Kerr et al., 2007).

Soil protection from erosion and water conservation

Grain leguminous crops offer ground cover that shields the soil from wind and water erosion, particularly when utilized as cover crops. Among the many ways legumes help conserve soil and water are by covering the soil both during and after cropping seasons. Crop leftovers spread out as mulch or active crops could be the source of soil cover. Reduced water evaporation results from high soil cover, which blocks the sun's heat from heating the soil directly (Vidigal et al., 2019). On the same plot of land, residues from grain and legume farming can also reduce soil erosion, retain soil moisture, and boost production (Vidigal et al., 2019).

Legumes regulate soil erosion in an intercropping system by shielding bare soil from raindrop impact. This allows the soil to retain water on the surface, accelerate surface runoff, and hide surface pores. Cowpea is the best cover crop for reducing soil erosion in the maize-cowpea intercropping system. In a similar vein, runoff was decreased by 20–30% when sorghum was grown alone and by 45–55% when cowpeas were grown monoculture. Particularly in intercrops of taller cereals with short legume crops, higher legume crops serve as wind barriers to short crops and reduce soil erosion (Nweke, 2018). Leguminous crops create a canopy that lowers nutrient runoff, preserves soil structure, and helps stop soil erosion.

Economic benefits to the farmers

Grain legumes have a significant impact on smallholder lives in Ethiopia and play a variety of roles at different levels, from farm households to national economies. A report by Ferede et al. (2014) states that the cultivation of grains and legumes provides a livelihood for over 8.5 million smallholder farmers. This is because most legumes often referred to as multipurpose produce multiple products and have multiple uses, either during growth or after harvest (Muoni et al., 2019). These benefits include improving food and nutrition security, supplying income, improving soil fertility, providing livestock feed, improving soil fertility, controlling soil erosion, water conservation, acting as a fuel source, and a range of other benefits. Contributions of various legume types and species to human food (kg ha^{-1}), livestock feed (kg ha^{-1}), and soil fertility (BNF ha^{-1}). To sum up, legume crops provide two basic benefits to farmers, (1) it is used as a source of income, legumes crops can be a lucrative crop for farmers due to their market demand and lower input costs for fertilizers and pesticides, (2) it is used for maintaining food security, it is a reliable source of protein and other nutrients, legumes play a key role in food security, particularly in developing countries where access to animal protein may be limited.

Empirical evidence from Ethiopia further demonstrates the ecological and economic value of legumes in mixed cropping systems: Maize-faba bean intercropping increases land productivity, boosts household income, and improves soil fertility relative to sole maize systems (Gidey et al., 2024). Maize-cowpea associations generate higher net revenues than monocultures, largely due to more efficient utilization of nutrients, space, and sunlight (Kussie et al., 2024). Sorghum-haricot bean intercrops enhance soil microbial activity, stabilize yields, and strengthen system fertility (Ashenafi et al., 2025). Despite these advantages, large yield gaps persist across Ethiopia's major cereal and grain legume crops. Current farmer yields remain far below their water-limited potential, with wheat, maize, sorghum, and common bean producing only about 26.8%, 19.7%, 29.3%, and 35.5% of potential yields, respectively (Belachew et al., 2022). Adoption of improved cultivars alongside better nutrient management and inoculation practices has been shown to raise yields by 24–160%, often doubling or tripling productivity (Belachew et al., 2022). Moreover, cereal-legume intercropping and rotation systems further increase yields, suppress pests, and reduce reliance on synthetic fertilizers.

Conclusion

Food legumes are the perfect crops to cultivate in order to achieve the developmental goals of decreasing poverty and hunger, improving human health and nutrition, and strengthening ecosystem resilience because of their varied and significant functions in farming systems and the diets of the disadvantaged. Incorporating legumes into production systems is necessary to guarantee the resilience and sustainability of agricultural livelihoods. Given this, it is imperative to comprehend the unique traits of each legume and how they function in an agricultural system, as this is a potential means of resolving the problems associated with low crop yields and raising sustainable output. Therefore, improving soil health and guaranteeing sustainable crop production in Ethiopia require the incorporation of grain leguminous crops into agricultural systems. By improving soil fertility, structure, and organic matter content, these crops support more resilient and productive farming systems, benefiting both the environment and the farmers. Promoting the cultivation of leguminous crops, along with continued research and extension services, can further advance sustainable agricultural practices in Ethiopia, contributing to the country's food security and environmental sustainability goals. Regarding the sustainable crop production, breeding programs focused on developing climate-resilient legume varieties can help mitigate the impacts of climate change on crop production. Besides these, varieties with improved drought tolerance, disease resistance, and adaptation to changing environmental conditions can ensure more stable yields and sustainable crop production.

Implications for research and policy

i). Advancing the development of legume varieties that are tolerant to drought, heat, and emerging pests and diseases is critical for Ethiopia's smallholder farming systems. Research should focus on breeding climate-smart cultivars adapted to diverse agroecologies, ensuring stable yields under variable environmental conditions, and addressing both nutritional quality and market preferences, ii). Maximizing biological nitrogen fixation through the effective use of rhizobium inoculants is essential for improving soil fertility and reducing dependency on synthetic fertilizers. Systematic evaluation of inoculant strains under local soil and climatic conditions is needed to identify the most effective combinations for different legume crops, ensuring consistent agronomic and economic benefits, iii). Understanding the economic value of legumes within integrated crop-livestock systems is crucial for informing policy and investment decisions. Research should quantify the contributions of legumes to household income, livestock feed, soil fertility, and overall farm resilience, providing evidence to guide farmers, development agencies, and policymakers in promoting legume-based production systems, Iv). Despite their benefits, legume adoption remains limited due to weak extension services, inadequate access to quality seeds and inoculants, and insufficient farmer knowledge. Strengthening farmer education programs, participatory demonstrations, and extension delivery mechanisms is essential to improve adoption rates, support informed decision-making, and enhance the sustainability of legume-based systems.

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