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Role of legumes in enhancing soil fertility: A sustainable approach to soil health and crop productivity

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Abstract

Maintaining soil condition is essential to ensuring the sustainability of agriculture. Soil health and fertility are diminishing, which makes feeding the world's population one of the biggest concerns of our day. The integrity of the soil may be harmed by the incautious use of synthetic fertilizers. Furthermore, the manufacture of chemical fertilizers pollutes the environment because it is associated with the release of greenhouse gases into the atmosphere. To enhance soil health and ease the adverse impacts of global warming, incorporating legumes into farming practices could be a valuable approach in light of global warming and climate change. Legumes are crops with several uses; they can be used to make grains high in protein, fix atmospheric nitrogen in the soil by biological means and increase the number of helpful bacteria in the soil. A considerable section of the Indian population has both chronic energy shortage and protein energy malnutrition due to the high cost of most animal food products, which makes them unaffordable for the rural poor. The reliance on foreign fertilizer imports for food crop production is evident in statistics on food demand and fertilizer requirements. But in addition to providing the protein and energy that humans require, legume crops may also be crucial in boosting the amount of nitrogen produced locally. By excreting organic acids from their roots, many legumes not only improve soil fertility but also have the ability to solubilize phosphate that would otherwise be unavailable. The significance of promoting legumes in the framework of national food security is discussed in this review paper.

Keywords: Legumes, soil fertility, intercrop, soil health, agriculture sustainability

Introduction

The foundation of developing countries is agriculture, which places a strong emphasis on crop yield and the appropriate and efficient use of natural resources to ensure the efficient provision of food and nutritional security. A farm's cropping pattern and the way it interacts with other agricultural resources to determine its composition are collectively referred to as the cropping system in a broader sense. Due to institutional backing and promotional efforts, wheat and rice dominated cropping systems following the start of the green revolution (Maitra, 2020a) ^[45]. Providing food and nutrition safety for the world's continuously increasing population is the challenge faced by modern agriculture. By 2030, it's projected that the world's population will reach 8.55 billion, growing to 9.77 billion by 2050 and 11.18 billion by 2100, as projected by the UN. This population surge will inevitably drive a higher demand for food. One in nine people on the planet, or approximately 795 million out of the 7.55 billion total are thought to be at risk of starvation (UN 2015). Approximately 782 million of individuals, or 12.5% of the total population in the region, reside in developing nations (UN 2015), highlighting the critical role that agricultural development plays in these numbers. As a result, agriculture is under immense pressure to manage the world's expanding population's needs for food and nutrition, reduce the negative consequences of climate change, and enhance the quality of the soil and natural resource we rely on (Lal 2015; Meena *et al.* 2015a) ^[38]. Legumes must be included in cropping systems in order to promote balanced food and nutritional security, as well as soil sustainability (Nees *et al.* 2010) ^[52]. The rapid increase in human activities that prioritize the exploitation of natural resources is causing growing concerns about the long-term viability of agriculture.

As we push these resources to their limits, there are serious questions about whether current farming practices can sustain future food needs. This issue has been highlighted by various studies and reports, including those by Verma *et al.* (2015a) [72], Lampkin *et al.* (2015) [39], and the FAO (2017), which underscore the urgent need to address these challenges to ensure agricultural sustainability.

For the sake of the future generations' well-being, it is crucial to consider the soil's overall fertility and production as well as the agro-ecosystem (Chen *et al.*, 2011, Stronge *et al.*, 2020) [14, 70]. Growing legumes could be a good choice because the crop has several advantages for agriculture, including improving soil health for sustainable agriculture.

Legumes

In the world, legumes rank as the second most significant food source, following cereals. Another viable, pricey meat substitute is thought to be legumes. Leguminosae or Fabaceae is the family that legumes belong to, and they yield seeds in pods. The third-largest family in the kingdom of plants is this family of legumes. Pulses are the second group of legumes, and oil seeds are the first group. It is well recognized that legumes are essential to a human diet (Arya *et al.*, 2020) [6]. The nitrogen-fixing symbiotic bacteria found in legumes' roots are responsible for converting nitrogen gas into ammonium, which the plant uses for protein synthesis. Incorporating legumes into cropping systems without delay is essential for ensuring food security, supporting agricultural practices, and enhancing nutrition. Legumes are known for their high protein content, partly due to their efficient photosynthesis. They are vital not only for enriching the soil but also for combating malnutrition, especially in resource-limited countries (Nees *et al.*, 2010) [52]. Legumes play a critical role in nourishing the land and eliminating malnutrition, particularly in nations with limited resources.

Legumes are included in the family Fabaceae. Along with the Asteraceae and Orchidaceae families, it is the third biggest family of angiosperms on Earth with 650 genera and 18,000 species

(ILDIS 2017). With 126–660 g of carbs, 180–430 g of protein, 7–400 g of fat, 0.9–2.4 g of calcium, 28–115 mg of iron, 13–39 mg of riboflavin, 3–99 mg of thiamine, and 7–64 g of dietic fibers in a kilogram of dry matter, legumes offer significant advantages over many other food sources in terms of nutrition (Berihun and Molla, 2017) [9]. When incorporated into cropping systems, legumes can enhance soil health, productivity, and sustainable farming (Dhakal *et al.*, 2016) [18]. The most extensively grown legume crop globally is soybean. However, the cultivation and spread of major grains is far more extensive than that of pulses because of a more intensive and specialized production system (Preissel *et al.*, 2015) [57]. Pulses make up the largest portion of the world's dietary protein requirements of 34 per cent. (Schuster, 2013) [63].

Moreover, certain necessary amino acids can be found in legumes (Margier *et al.*, 2018) [47]. In addition to their many beneficial roles as a source of nutrient-dense food for humans and cattle, they also improve the soil's nitrogen pool, soil organic carbon, and crop productivity. As such, legumes need to be used in cropping systems in a different way in order to achieve sustainability. (Dhakal *et al.*, 2016) [18]. Today, the production of grains and legumes continues to grow thanks to advanced agricultural techniques such as organic farming, reduced tillage, the use of biofertilizers, and precise input management (Meena *et al.*, 2016) [34]. Legumes are particularly effective at boosting soil levels of key nutrients like nitrogen,

phosphorus, potassium, calcium, and magnesium, which is much more beneficial than monoculture crops. This can help offset rising agricultural costs, particularly those related to fertilizers (Huang, 2007; Stagnari *et al.*, 2017) [30, 68]. When integrated into organic farming systems, legumes contribute to sustainable practices and reduce the need for chemical inputs (Verma *et al.*, 2015a, b) [72–13]. Additionally, legumes can enhance farming systems by lowering greenhouse gas emissions, improving soil carbon storage (Reckling *et al.*, 2014) [60], reducing fertilizer and tillage needs, minimizing water body eutrophication, and decreasing soil acidity (Clark *et al.*, 2013).

Legumes as intercrop

Under the changing climate scenario, legume intercropping has great potential to sustainably increase food production and help feed the world's expanding population. (Iqbal *et al.*, 2019; Jhariya *et al.*, 2021) [31, 32]. Legumes enhance the soil by adding nitrogen, which benefits the crops grown alongside them in intercropping systems (Maitra *et al.*, 2019) [46]. Since legumes fix nitrogen from the air, they reduce competition for nitrogen from the soil, making this a highly efficient practice in mixed cropping setups.

According to Smith *et al.* (2016) [67], The complementary interaction in diverse land-use systems helps minimize competition for growth resources among species. It promotes the production of protein-rich food and fodder, supports steady crop yields even under challenging environmental conditions, enhances soil fertility, and reduces the need for costly fertilizers. Pigeon pea is a common intercrop component in nearly all dual legume intercropping systems in India. Intercropping refers to cultivating multiple crops on the same plot of land simultaneously within one growing season., often arranged in a specific row pattern (Brintha and Seran, 2009) [64]. This method aims to achieve various ecological benefits, such as promoting species interactions, supporting natural processes, enhancing biodiversity, and reducing farmers' risks from climate variability (Lithourgidis *et al.*, 2011; Kumar *et al.*, 2016) [43]. Typically, the crops in an intercrop system come from distinct species and families, with one serving as the chief food source and the other providing additional benefits like nitrogen fixation, biomass production, soil improvement, or economic advantages. Compared to monocropping, using legumes in an intercropping system can lead to higher yields from the same area and greater resource efficiency (Inal *et al.*, 2007). The synergy between legumes and non-leguminous plants often results in better yields because legumes enhance soil health through their relationship with rhizobia, which improves soil functions (Fustec *et al.*, 2010) [25].

Cereals

Cereals are known for their high nutrient demands, often depleting the topsoil of essential nutrients (Ali *et al.*, 2012; Layek *et al.*, 2014a) [2, 42]. To counteract this depletion and improve soil health, intercropping legumes such as soybean (*Glycine max*) or groundnut (*Arachis hypogaea*) with cereals like rice (*Oryza sativa*), maize (*Zea mays*), sorghum (*Sorghum bicolor*), or pearl millet (*Pennisetum typhoides*) can be highly beneficial. Legumes are particularly effective in this regard because of their capacity to convert atmospheric nitrogen, which not only enhances soil fertility but also reduces the risk of crop failure from nutrient deficiencies.

Additionally, intercropping legumes with cereals can help manage moisture stress more effectively. For instance, during years of low rainfall, legumes can improve soil structure and

moisture retention, while in periods of heavy rainfall, their presence can help with water management. This balanced approach to moisture management helps to mitigate the adverse effects of fluctuating weather conditions.

Legumes and cereals, with their varied growth patterns and root structures, can better exploit the soil and climate conditions compared to when they are grown in isolation (Layek *et al.*, 2012; Ram and Meena, 2014) ^[41]. The different morphology of these plants allows them to access nutrients and water from different soil layers and spaces, leading to a more efficient use

of available resources.

For successful cereal-legume intercropping, it is essential to carefully manage several factors to minimize competition and maximize benefits. Key considerations include ensuring adequate space for each crop, optimizing plant density, coordinating the maturity periods of the component crops, and designing an effective geographical layout. By addressing these factors, farmers can achieve a productive and resilient intercropping system that enhances overall crop yields and promotes sustainable agricultural practices.

Table 1: Impact of various systems of intercropping maize and legumes on soil moisture, system yield, and water and energy usage efficiency (data source: Choudhary and Kumar, 2016).

Cropping System	System productivity (t/ha)	Soil moisture(mm)	WUE (kg/ha/mm)	Energy productivity (kg/MJ)	Energy output: Input ratio
Maize	4.0	-25.5	4.7	0.32	10.1
Soybean	3.5	-101.9	4.8	0.43	7.0
Groundnut	4.2	-124.0	7.2	0.61	5.5
Maize+ soybean (1:1)	4.5	-53.4	5.4	0.30	10.0
Maize + soybean (1:2)	5.3	-70.9	6.2	0.31	9.5
Maize+ soybean (1:5)	5.6	-91.7	6.5	0.41	10.8
Maize+ groundnut (1:1)	4.6	-61.6	5.6	0.30	9.3
Maize+ groundnut (1:2)	5.7	-81.8	6.8	0.33	9.1
Maize+ groundnut (1:5)	6.2	-103.0	7.3	0.44	9.9

Oilseeds

Legume and oilseed intercropping, compared to growing these crops separately, enhances soil fertility, improves nutrient-use efficiency, and reduces the need for additional fertilizers, all while providing better yields and economic returns (Dowling *et al.*, 2021) ^[19]. Traditionally, intercropping has primarily been practiced on smaller subsistence farms in tropical and subtropical regions, where it's easier to manage a diverse range of species. This is partly because large-scale farming operations, which rely on specialized technology, find it challenging to handle multiple crops simultaneously. However, by incorporating oilseeds and legumes instead of the more common cereal-legume combinations, many of the earlier challenges associated with intercropping can be overcome. Since both oilseeds and legumes are broadleaf plants, they can fit well into cereal rotations, offer more flexibility for in-season herbicide applications, these systems can be integrated into current farming practices, allowing crops to be planted and harvested together with minimal changes to existing equipment. (Fletcher *et al.*, 2020; Dowling *et al.*, 2021) ^[19]. Despite its benefits, oilseed-legume intercropping is still not widely adopted in broadacre agriculture (Alcon *et al.*, 2020; Fletcher *et al.*, 2020). Most research has focused on regions like China, northern Europe, and Canada, with limited data available for Mediterranean climates (Dowling *et al.*, 2021) ^[19]. This lack of research means that farmers in Mediterranean Europe, southern, and western Australia have limited guidance on how to implement this practice effectively. To address this gap, they investigated how different levels of fungicide and fertilizer affect the economic and yield performance of chickpea-linseed and chickpea-canola intercrops. Their goal was to assess whether oilseed-legume intercropping could be a cost-effective, low-input strategy for large-scale farming in Mediterranean environments.

Legume's Role in Soil Sustainability

Intercropping systems incorporate the principles of sustainable agriculture, which are founded on three main pillars: ecological, social, and economic sustainability. This approach aligns with

the global shift towards low-input farming to minimize environmental issues caused by excessive agricultural inputs, especially high nitrogen levels. By reducing competition for resources and making efficient use of what's available, intercropping enhances productivity—especially for non-legume crops—improves yield stability under challenging conditions, and fosters beneficial root interactions while requiring fewer nitrogen and phosphorus inputs (Lithourgidis *et al.*, 2011) ^[43]. Intercropping also benefits pasture quality, prevents soil erosion, boosts soil fertility, supports biodiversity, and provides a safeguard against crop failures (Sun *et al.*, 2013). Additionally, it helps to reduce pest and disease problems (Dwivedi *et al.*, 2015). Legumes, in particular, play a crucial role due to their symbiotic relationship with rhizobium bacteria, which enables them to fix atmospheric nitrogen into the soil. This natural nitrogen fixation makes legumes a valuable alternative to synthetic fertilizers, contributing significantly to reducing the need for chemical nitrogen sources (Bedoussac *et al.*, 2015). The growing production of legumes could have significant and possible advantages. According to Huggaard-Nielsen *et al.* (2007), legumes are crops that improve soil health and should be a crucial part of farming systems. Most short-term studies show positive results, highlighting the value of incorporating legumes into crop rotations to improve soil health (Binder and Wiek, 2007) ^[11]. As our global population is increasing at fast pace, it is putting strain on food security. At the same time, our water and soil resources are being pushed to their limits and are showing signs of decline. Factors such as soil degradation, pollution, climate change, declining soil fertility, industrialization, urbanization, and rising fertilizer costs are all contributing to the decline in soil health. The rapid growth and intensification of agriculture have sparked major concerns about whether our farming practices can remain sustainable in the long run (Verma *et al.*, 2015a) ^[72].

Legume is currently used as a soil conditioner. These benefits for soil health, however, need to be measured and their mechanisms comprehended. Legumes are highly valued in conservation agriculture and sustainable farming systems due to their beneficial properties. This approach emphasizes

maintaining permanent soil cover, minimizing soil disturbance, and practicing crop rotations (Hobbs *et al.*, 2007). Legumes contribute significantly by fixing nitrogen into the soil and improving the quality of organic matter, notably with their favorable carbon-to-nitrogen (C/N) ratio. Additionally, certain legume species develop deep root systems that enhance water infiltration into lower soil layers and aid in nutrient solubilization through their root exudates and uptake/recycling processes.

Nutrient availability and uptake

Legume-based cropping systems enhance soil fertility in several ways. They boost soil organic carbon and humus levels, improve the availability and uptake of nitrogen (N) and phosphorus (P), and support the development of legume nodules in the rhizosphere release hydrogen gas as a by-product of biological nitrogen fixation. (BNF) (Stagnari *et al.*, 2017) ^[68]. The availability and absorption of nutrients by plants largely rely on the conditions in the root zone, such as the nutrient levels and the soil's capacity to restore those nutrients (Makoi *et al.*, 2013). Nitrogen and phosphorus are vital nutrients found in both the soil and the atmosphere, but they are often unavailable in forms that plants can readily use. This makes them common limiting factors for plant growth and development (Mmbaga *et al.*, 2014).

Stagnari *et al.* (2017) ^[68] identified two key contributions of grain legumes to agriculture: (1) the "nitrogen effect," which involves nutrient provision through BNF, particularly beneficial when nitrogen fertilization is low, and (2) The "break crop effect" refers to a range of benefits, including boosting soil organic matter and structure, increasing phosphorus availability, enhancing soil water retention, and lowering the pressures of diseases and weeds. Thus, legumes have the greatest impact when they are part of diverse cropping systems.

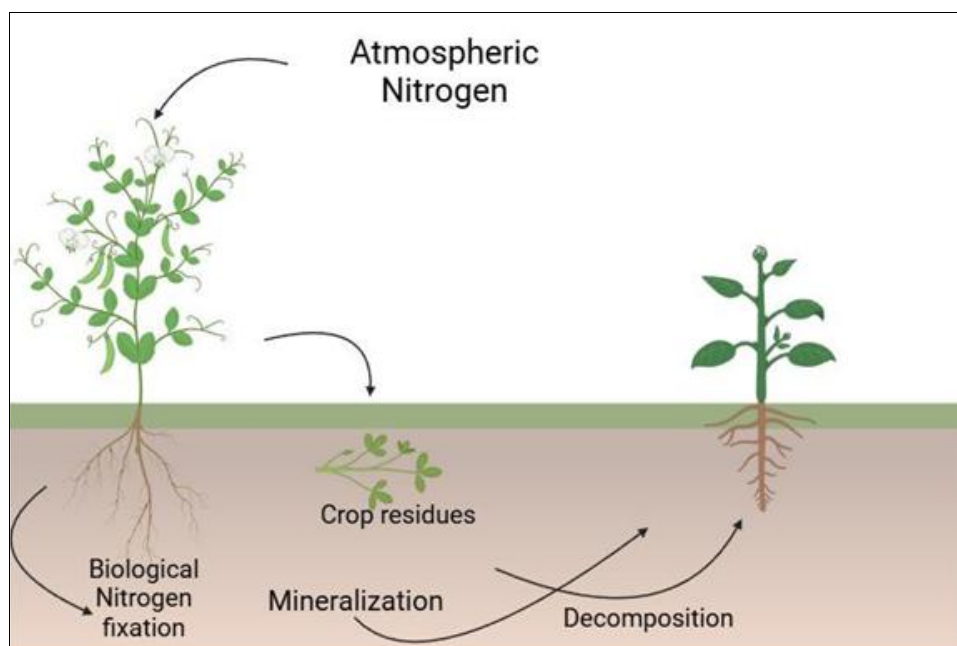
Legumes have evolved ways to make phosphorus more

available, often by forming beneficial partnerships with rhizobia bacteria. For example, Stagnari *et al.* (2017) ^[68] found that intercropping legumes led to greater phosphorus availability in the rhizosphere compared to growing them alone.

Legumes's Beneficial Effect on Improving Soil Health

The symbiotic relationship between legumes and rhizobia enables legumes to fix nitrogen in the soil, enhancing soil quality and boosting organic carbon levels. Intercropping legumes with other crops is an effective strategy for diversifying and intensifying agricultural systems (Raji and Dörsch, 2020). When legumes are paired with cereals, the different root systems and rhizosphere activities often result in better soil coverage and more efficient resource use (Layek *et al.*, 2018). These legume-based intercropping systems not only enhance soil fertility but also improve water retention in the root zone due to the availability of high amount of organic content (Tirado and Cotter, 2010). The improved yields of these mixed crops are often linked to better nutrient availability, such as increased levels of mineral nitrogen and phosphorus, benefiting both cereals and legumes.

Incorporating legumes into cropping systems, either as green manure or through diverse cropping practices, enhances soil organic matter and supports a richer soil microbiome (Kumar *et al.*, 2016). Relying solely on continuous cereal cropping tends to degrade soil health and lead to nutrient deficiencies. Adding legumes like moong or soybean can address these issues and help maintain soil fertility and productivity (Dhaliwal *et al.*, 2011; Singh *et al.*, 2011). For example, intercropping lentils and isabgol can mitigate drought effects, boost nitrogen levels in isabgol plants, and support the growth of both crops. Beyond these advantages, intercropping also reduces the risk of crop failure, increases soil organic carbon, diversifies farm income, and often requires fewer pesticides (Asgharipour and Rafiei, 2010).



Soil physical health

Green manures are plants grown specifically to be incorporated into the soil to enhance its fertility and structure. These plants are typically left undecomposed initially and can include a variety of species, though legumes are commonly used due to their beneficial properties. They are either tilled into the soil or

used as surface mulch, especially in conservation agriculture, where their primary role is to improve soil quality through the decomposition of their biomass. This decomposition process releases a range of nutrients into the soil, supporting plant growth and enhancing overall soil health. The key benefit of using legume-based green manures is their capability to convert

atmospheric nitrogen into a form that enriches the soil. Legumes form a symbiotic relationship with rhizobia bacteria, enabling them to capture nitrogen from the air and convert it into a usable form for plants, significantly increasing the nitrogen content in the soil. This is particularly valuable because nitrogen is a critical nutrient for plant growth. By integrating legumes into crop rotations or as green manures, farmers can improve soil nitrogen levels naturally, which enhances soil fertility and can lead to increased agricultural yields (Murphy-Bokern *et al.*, 2017)^[60].

Along with supplying nitrogen, legume green manures help make other vital nutrients more available, including macronutrients like phosphorus (P) and potassium (K), as well as micronutrients such as zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu). This process helps to alleviate nutrient deficiencies and supports balanced soil fertility. By improving nutrient retention and reducing soil erosion, legume green manures also play a role in mitigating environmental impacts and supporting sustainable farming practices (Meena *et al.*, 2018).

Soil physical characteristics, such as texture, bulk density, and porosity, are crucial for effective water management and overall soil health. These characteristics influence various water-related processes, including aeration, runoff, erosion, water retention, and infiltration. Legume cover crops improve these physical properties by adding substantial biomass to the soil. This biomass serves as a source of organic matter, which improves soil structure and functionality. As the legume biomass decomposes, it forms soil aggregates, improves soil porosity, and increases the soil's capacity to hold water. These changes contribute to enhanced water infiltration and decreased surface runoff, which can help to prevent soil erosion and enhance the soil's ability to retain moisture (Lal, 2015)^[38].

Legumes also positively impact soil organic matter and aggregation. By enhancing the formation and stability of soil aggregates, legumes improve soil texture and structure. This leads to increased water infiltration rates and reduced soil compaction. The organic matter from legume cover crops not only supports the physical health of the soil but also aids in maintaining or increasing soil organic carbon levels. This is crucial for long-term soil fertility and health, as organic carbon contributes to soil structure, nutrient availability, and microbial activity (Liang *et al.*, 2010; Meena *et al.*, 2017; Srinivasarao *et al.*, 2012)^[7].

Incorporating green manures, especially legumes, into agricultural systems provides numerous benefits. These include enhancing soil fertility through nitrogen fixation, improving nutrient availability, supporting soil structure, and increasing water retention. By integrating legume green manures into cropping systems, farmers can promote more sustainable and productive agricultural practices, while also mitigating environmental impacts and supporting long-term soil health.

Soil chemical properties

The transport and accessibility of nutrients within the soil, which are crucial for boosting crop yields, are closely linked to its chemical characteristics, including pH, cation exchange capacity (CEC), soil organic carbon (SOC), base saturation, buffering capacity, and nutrient concentration (Meena *et al.*, 2015a)^[49]. Legumes have a high pH when added as green manure (Kiiya *et al.*, 2010), which affects soil acidification caused by the cycles of carbon (C) and nitrogen (N). Legumes have a high pH when added as green manure (Kiiya *et al.*, 2010), which affects soil acidification caused by the cycles of carbon (C) and nitrogen

(N). Legumes raise soil microbial activity and regulate the nitrogen cycle process by altering the pH of the rhizosphere in the cropping system (Oelbermann *et al.*, 2015)^[61]. The inclusion of legumes to soil not only increases the amount of nitrogen but also significantly increases the amount of organic matter, vital nutrients, and atmospheric carbon dioxide sequestration (Turnbull and Bowman 2002; Pikul *et al.*, (2008); Ogunwale *et al.*, (2010); Sharma and Behera (2009); Lal, 2015)^[38].

Soil microbes

When legumes are integrated into various cropping systems, they enhance soil fertility. Biological nitrogen fixation (BNF) helps these legume crops to use nitrogen from the atmosphere, which is very important in agricultural systems where there is short supply of nitrogen fertilizers (Meena *et al.*, 2018; Lengwati *et al.*, 2020). Legume crops for example lablab, groundnut, soybean, common bean, and cowpea serve as essential hosts for rhizobia to do biological nitrogen fixation (BNF). These legumes not only provide fixed nitrogen to the cropping system but also aid in solubilizing insoluble phosphorus (P), enhancing soil microbial activity, improving soil structure, replenishing organic matter, and suppressing weed growth (Stagnari *et al.*, 2017)^[68]. Legumes (such as red clover, alfalfa, lentil, pea, chickpea, and fava bean) provide between 21 and 389 kg ha⁻¹ of BNF (Vasconcelos *et al.*, 2020). Stagnari *et al.* (2017)^[68] found that different legume species, soil characteristics, climates, cropping methods (such as monoculture, mixed culture, crop rotations, etc.), and soil management techniques all affect the amount of BNF and its corresponding contribution.

Productivity

For developing nations, reaching sustained productivity is a major challenge that is crucial to easing limits associated to soil (Verma *et al.*, 2015a)^[72]. According to Wichern *et al.* (2007)^[76], the BNF is a viable environmentally acceptable source of nitrogen that may be used to maximize fertilizer application and maintain agricultural production. Legumes boost soil N stock by supplying substantial amounts of nitrogen to the soil, even if the majority of their fixed nitrogen is harvested as grain yield (Garg and Geetanjali 2007; Dhakal *et al.* 2015)^[17]. Soil bacteria are a crucial part of earth's biodiversity and have several essential roles in maintaining soil health. They are key players in breaking down organic matter, recycling nutrients, fixing nitrogen, and enhancing soil structure (Ludwig *et al.*, 2015; Gong *et al.*, 2019)^[44, 28]. Their activities help to keep soil fertile and functioning well, supporting healthy plant growth and overall ecosystem balance.

Legumes have the ability to increase agricultural yield, which makes them a viable solution for the problems associated with poor productivity. Legumes offer a wide range of benefits for increasing agricultural productivity. Furthermore, Meena *et al.* (2016)^[48] state that the sustainable use of natural resources promotes soil quality and the environment.

Legume intercropping to control pests and diseases and insects in component crops

Diseases, weeds, and insect pests are serious issues for the agricultural production system, particularly in exhaustive and monoculture practices. (Siddique *et al.*, 2012)^[65]. Legume intercropping is a sustainable method of reducing the incidence of illnesses and insect pests while also reducing the biomass of weeds. Climate change may impact the amount and quality of agricultural products, as well as the location and intensity of pest outbreaks (Kumar *et al.*, 2017, a,b). Legume intercropping

diversifies planting systems by boosting the number of predators and parasites that benefit pests, while also keeping the population of damaging pests below the level of economic threshold (Maitra *et al.*, 2019) ^[46]. Legume intercropping also closely adheres to the "push and pull" theory, which is a successful weed- and insect-control method (Hassanali *et al.*, 2008; Xu *et al.*, 2017) ^[29]. By enhancing the functional diversity

of the system, legume intercropping reduces the occurrence and multiplication of pathogens that cause disease (Kumawat *et al.*, 2020a) ^[37]. According to research, intercropping maize with legumes considerably decreased the populations of harmful pests such as corn borer, budworm, stalk borer, and leafhopper, while increasing the populations of beneficial insects (Seran and Brintha, 2010) ^[64].



Productivity of Interplanted Legume

In an onsite study carried out in New Delhi, India, researchers found that when soybean was interplanted with pearl millet rather than maize or sorghum, there was a noticeable decrease in both the number of pods per plant and the number of seeds per pod (Layek *et al.*, 2014a, b) ^[42]. This suggests that the choice of companion crops can impact soybean yield outcomes.

This might be explained by the intense rivalry that pearl millet and soybean exhibited, as evidenced by the tall, lanky plants, fewer branches, decreased buildup of dry matter, etc., which resulted in fewer pods on each plant (Layek *et al.*, 2014a) ^[42]. Additionally, the amount of seeds per pod may have decreased due to general competition. Due to its wide spacing and non-tillering nature, maize and sorghum had less competition from soybean than from pearl millet. The yield parameters given in

the table was slightly impacted by the N levels as well. In soybean intercropping, the number of pods per plant, number of seeds per pod, and biological yield were greater when no extra nitrogen was applied to the cereal crops. However, these yield measures decreased as the amount of nitrogen added increased. This suggests that higher nitrogen levels may negatively affect soybean yields in these intercropped systems.

The primary reason for this could be the improved development of cereal intercrops with rising N levels, which subsequently led to more rivalry with soybean and a decline in yield metrics. When compared to growing soybean alone, those cultivated alongside intercrops like pearl millet had lower yields, especially when their cereal counterparts received a higher nitrogen application. (Layek *et al.* 2012) ^[41].

Table 2: The yield characteristics, yield, and economics of an intercropping system based on soybeans in a semiarid region of India (Layek *et al.*, 2012) ^[41]

Treatment	Pods/ plant	Seeds/ pod	Grain yield (Mg/ha)	Biological yield	Net return (\$/ha)
Sole soybean 30N	22.20	2.50	1.58	4.66	176.7
Soybean 30n + maize 0N	18.80	2.30	1.27	4.15	152.6
Soybean 30n + maize 30N	16.40	2.15	1.12	4.00	219.4
Soybean30n + maize 45N	15.60	2.14	1.09	4.01	239.4
Soybean30n + maize 60N	14.85	2.17	1.04	3.87	247.0
Soybean 30n + sorghum 0N	18.45	2.30	1.20	3.99	138.6
Soybean 30n + sorghum 30N	16.10	2.17	1.04	3.76	206.0
Soybean 30n + sorghum 45N	15.45	2.13	1.01	3.70	226.4
Soybean 30n + sorghum 60N	14.20	2.13	0.98	3.56	220.4
Soybean 30n + pearl millet 0N	12.35	2.13	0.74	2.65	57.2
Soybean 30n + pearl millet 20N	11.10	2.07	0.71	2.81	143.2
Soybean 30n + pearl millet 30N	10.95	2.04	0.68	2.63	148.3

Soybean 30n + pearl millet 40N	10.20	2.04	0.66	2.58	144.9
SEm±	0.55	0.05	0.04	0.18	5.2
LSD(p=0.05)	1.65	0.15	0.10	0.52	1465

Conclusion

Due to its short growing season, legumes can be produced under resource-constrained circumstances all over the world. Legumes improve soil health and provide food and nutrition security, as well as ecological soundness and the development of an effective agroecosystem, reduce soil erosion, improve soil health through biological nitrogen fixation, increase soil organic carbon and nitrogen stock, and sequester carbon in the soil. All these advantages can be traced back to incorporating legumes into cropping systems. Enhancing soil health promotes ecological sustainability and guarantees feed, food, and nutrient security. Including legume crops reduces the widespread use of synthetic N fertilizers while also boosting biodiversity. By reducing the occurrence of insect pests, diseases, and weeds, increased crop diversity enhances soil biodiversity and establishes a supportive microclimate, preserve plant health and lower the chance of crop failure. Rhizobium's bioremediation activity enhances the bioavailability of constituents and helps in solubilizing insoluble phosphorus.

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