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REVIEW ARTICLE Agricultural Reviews

Impact of Maize-legume Intercropping on Soil Fertility Management: A Review

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10.18805/ag.R-2709

ABSTRACT

This review paper aims to gather significant literature on the influence of maize-legume intercropping in soil fertility management based on research conducted in various parts of the world at various times. The review titled 'Impact of maize-legume intercropping in soil fertility management was organized using relevant materials such as empirical studies, case reports and meta-analyses that highlight the benefits and challenges associated with this agricultural practice. By synthesizing these findings, the paper seeks to provide a comprehensive overview of how maize-legume intercropping can enhance soil health, improve crop yields and contribute to sustainable farming practices as journal article reviews and brief communications. Intercropping is a valuable agronomic approach that allows efficient use of resources such as water, soil nutrients and light, resulting in increased yield when compared to monocropping. This review provides researchers and practitioners with a thorough understanding of the benefits of intercropping in sustaining soil fertility, which greatly contributes to crop output. This review investigated and clarified the various ecological services provided by maize-legume intercropping systems. As different research studies conducted across the world illustrate, intercropping promotes nutrient availability and uptake by plants, thus increasing production. This knowledge will assist farmers in India in better understanding how to employ cereal-legume intercropping systems what benefits to raise yields, improve socioeconomic situations and promote conservation agriculture practices.

Key words: Greenhouse gas, Intercropping, Monocropping, Nutrient management, Soil health.

Abbreviations: BD: Bulk density; BNF: Biological nitrogen fixation; C: Carbon; CA: Conservation agriculture; CT: Conventional tillage; GHG(s): Green house gases; OM: OM Organic matter; SOC: Soil organic carbon; ZT: Zero tillage.

Despite a growing population and several climate-related stresses, India is a proud nation with independence in food grain production and long-term food security. However, satisfaction is impossible to achieve because the country continues to face enormous challenges in the pulses and cereal industries. A gap of approximately 56% between food availability and demand has to be filled by 2050 while maintaining agriculture productivity, environmental quality and soil health (Searchinger *et al.,* 2019). The global population is expected to reach 9.4 to 10.2 billion by 2050, with food demand increasing by more than 22-34% [World Water Development Report (WWDR), 2023]. Furthermore, approximately 800 million people are hungry or malnourished.

As a result, providing food and nutritional security for this rapidly growing population will be a major problem in the future years (Fliebach *et al.,* 2007). Furthermore, increasing land degradation increases greenhouse gas (GHG) emissions and decreases the rate of carbon (C) absorption in the soil, both of which contribute to climate change. (Roy *et al.,* 2022). Nearly 25% of the total land surface has been degraded globally, affecting approximately 3.2 billion people, primarily small and marginal farmers with low socioeconomic status.

Intensive and unsustainable crop production practices destroy fertile soils at a rate of 24 billion tons per year and if this trend continues, 95% of the global land surface might be degraded by the end of 2050 (Singh *et al.,* 2025). Furthermore, increased biotic and abiotic stresses caused by climate change may pose a severe threat to the food production system (Prakash *et al.,* 2020).

Legumes have a multifaceted impact in terms of enhancing soil fertility and establishing nutrient pools (Jhariya *et al.,* 2018). Legumes in cropping systems help to provide protein-rich food and feed, improve soil health, increase soil organic carbon (SOC), conserve soil and water and improve air quality (Stagnari *et al.,* 2017; Meena *et al.,* 2022). In India, pulses have long been considered the poor man's protein. Pulse availability per capita

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How to cite this article: Singh, U.K., Sujatha, H.T., Korav, S., Jadhav, K.P. and Adishesha, K. (2025). Impact of Maize-legume Intercropping on Soil Fertility Management: A Review. Agricultural Reviews. 1-11. doi: 10.18805/ag.R-2709.

Submitted: 15-05-2024 **Accepted:** 22-10-2024 **Online:** 24-02-2025

declined from 60.54 grams in 1950-51 to 53.00 grams in 2021-22, compared to the minimal requirement (ICMR requirements for sedentary activity) of 68.49 g/day and the WHO recommendation of 80g/day (Minhas, 2023). The country's pulse requirement is expected to be 32 million tonnes by 2030 in order to ensure self-sufficiency. Domestic production of nine annual oilseed crops would provide 13.69 million metric tonnes of vegetable oil by 2022. India is estimated to consume 23.45 million tonnes of vegetable oil between 2022 and 2023 (Minhas, 2023).

Intercropping is an important multiple cropping technique that has been widely used in impoverished and emerging countries. Intercropping is preferred over monoculture because it increases productivity by making better use of resources such as water, nutrients and sun energy (Singh *et al.,* 2023a).

Intercropping is a kind of mixed cropping that is defined as an agro-ecological system that involves growing two or more crops in the same plot of land (Bedoussac *et al.,* 2015). Since this ancient farming approach varies by region to region, the crops grown in this configuration are diverse and differ by species or cultivar. This approach is regarded as an environmentally benign cropping practice, as it is land-saving and may yield higher food quantity and diversity on less or equal area than crops grown in monoculture. The intercropping technique makes use of mutualistic relationships between crop species as well as changes in niche occupation over time and space (Francis, 1986), which frequently results in greater profitability and ecosystem benefits (Zhi *et al.,* 2007). Main objective of intercropping is to maximize total productivity per unit of space and time. There is abundant data to suggest that intercropping can boost total output over solitary cropping by making better use of resources like as water, fertilizer and sunlight. It has the potential to be more productive than monoculture (Singh *et al.,* 2023b). Intercropping has been used in smallholder cropping systems for hundreds of years (Banik *et al.,* 2006). In addition to yield increment and stability, the practice has been shown to provide a variety of ecosystem services such as conservation of soil microorganism biodiversity (Nicholls *et al.,* 2016), effective nutrient management (Punyalue *et al.,* 2018), weed suppression, pest control, pollination benefits and soil conservation (Jensen *et al.,* 2020). Furthermore, intercropping maize with legumes increased farm sustainability while mitigating climate change (Nicholls *et al.,* 2016), reduced soil erosion (Blanco-canqui *et al.,* 2015) and enhanced water conservation (Nicholls *et al.,* 2016). Intercropping may also necessitate greater field management effort, including as field preparation, seed mixing and additional labour throughout the crop produced and harvest process. Although numerous studies have demonstrated that intercropping can enhance production per unit of land, a few studies have shown that maize-legume intercropping can impair maize yield. For example, Yap *et al.* (2017) found that in a maize-legume intercropping system, maize yields are significantly lower than in a monocropping system. As a result, farmers that practice intercropping may trade higher overall yields for all crops cultivated in the intercropping system for lower maize yields in particular (Pierre *et al.,* 2022). Because of the beneficial ecosystem services, the traditional cropping system of the location is an appealing choice for the farming system of the particular region. More information about the current state of intercropping systems in India, including the benefits and drawbacks of this approach, is needed.

Maize-legume intercropping has been shown to preserve soil and water within specific land types (Anil *et al.,* 1998) and to produce a consistent yield (Lithourgidis *et al.,* 2006). Smallholder farmers typically plant cereal-legume intercropping due to the legume's ability to adapt to disintegrating soils and deteriorating soil health (Begam *et al.,* 2020). Legume's ability to fix atmospheric N in soil enhances soil fertility and decreases soil nutrient completeness (Fujita and Ofosu-Budu, 1996). Legumes are soil-amendment crops with significant soil-health benefits that must be included in farming systems (Dhakal *et al.,* 2016). Furthermore, recent evaluations have explored the possibility for employing intercropping systems to improve ecosystem services.

We reviewed the literature in order to offer an overview of the potential benefits and constraints of a maize-legume intercropping system, as well as the prospects for effectively using maize-legume intercropping systems to provide nitrogen (N) to crops, control weed populations, reduce pest and disease and minimize soil erosion. Furthermore, the implications on farm revenue and/or food security, as well as the issues associated with India's maize-legume intercropping system.

Intercropping systems improve nutrient availability and uptake

Intercropping's primary purpose is to maximize total productivity per unit of space and time. There is abundant data to suggest that intercropping can boost total output over solitary cropping by making better use of resources like as water, fertilizer and sunlight. It has the ability to outperform monoculture in terms of productivity. Intercropping strategies have been found to boost total crop production per unit area using a concept known as "overyielding" (Gliessman, 2007).

Farmers use the approach for a variety of reasons, including increased ecological efficiency and the capacity to mitigate the risk of crop failure of any one crop. Intercropping legumes, for example, can increase yield per unit area by making the greatest use of all available resources (nitrogen fixation from the legume species as well as weed suppression enhancement) that a single crop would be unable to utilise (Ram and Meena, 2014). Intercropping increases soil nutrient availability as shown in Fig 1 (Ma *et al.,* 2017). According to Ghanbari *et al.* (2010), maize-cowpea intercropping increases nitrogen, phosphate and potassium content when compared to maize monocultures.

Intercropping increased soil organic matter and total nitrogen concentration in another study (Cong *et al.,* 2015). Intercropping has been associated to higher ecosystem productivity and nutrient retention (Brooker *et al.,* 2015). Oberson *et al.* (2001) determined the fact from a field experiment on maize + soybean intercropping systems that legume-based cropping systems maintained greater organic and accessible P levels than non-legumes in rotation.

They also found that higher turnover of roots and above-ground litter in legume-based intercropping could provide steadier organic inputs and thus high P cycling and availability. Rain interception is projected to improve with multi-layered intercropping canopies, as is litter fall as a result of enhanced production and longer water retention, resulting in decreased surface runoff and enhanced soil nutrients. Chalka and Nepalia (2006) discovered that, intercropping maize with soybean reduced NPK depletion and boosted N absorption. On the other hand, Mucheru-Muna *et al.* (2010) indicated that, accelerated soil nutrient depletion, particularly for phosphorus, due to more effective soil nutrient consumption and greater removal through harvested crops. Increased nitrogen uptake in intercropping systems can occur both regionally and temporally (Singh *et al.,* 2025). When crops in an intercropping system have peak nutrient demands at different times, increasing root mass can increase spatial nutrient uptake while decreasing root mass can increase temporal nutrient uptake (Singh *et al.,* 2025a).

Intercropping promotes higher and significant N, P and K uptake in crops as compared to solitary cropping. Tripathi and Kushwaha (2013) discovered that, NPK uptake was significantly higher when pearl millet was intercropped rather than sole crop. Cereal-legume intercropping has been viewed as effective under low-nitrogen conditions which mainly because of complementarity for N uptake that this system provides (Pelzer *et al.,* 2012). Rhizobia bacteria in the roots of leguminous plants “fix” atmospheric N and incorporate it into the biomass which increases the amount of N in the system via the plant’s biomass and root exudates.

Cereals have been demonstrated to have complimentary N dynamics and can use a significant amount of the available N in the cropping system (Fan *et al.,* 2006). Besides from N complementarity, rhizosphere exudation of phosphatases and carboxylates is thought to help legumes to acquire phosphorus (P) from intercropped cereals (Singh *et al.,* 2025). Cereal and legume intercropping systems have also been found to use light resources more efficiently than monocropping systems. Improved radiation use efficiency (RUE) will directly affect crop biomass, resulting in greater grain growth and yield. According to Mahallati *et al.* (2015), maize RUE increased by 7 to 11% when compared to solitary maize due to lower N competition in maize-bean intercropping systems.

The effects of intercropping on soil qualities

Physical properties of soil

Soil erosion, nutrient mining and SOC reduction are key causes of land degradation and loss of soil physical qualities, resulting in low agronomic yields in agricultural systems. Furthermore, input-intensive agricultural systems hasten the depletion of soil fertility and perpetuates nutritional insecurity (Lal, 2017). In this regarding, legume intercropping is an advanced technique for improving soil physical qualities and sustaining agricultural productivity (Begam *et al.,* 2020). Contribution of legume crops to soil organic matter SOM) will improve air circulation, water retention and buffering constraints along with making the land more productive.

According to Layek *et al.* (2018), SOM chelates soil both physically and chemically, enhancing soil aggregation and therefore stabilizing and resisting disintegration. Grain legume residues with a low C-N ratio degrade faster and

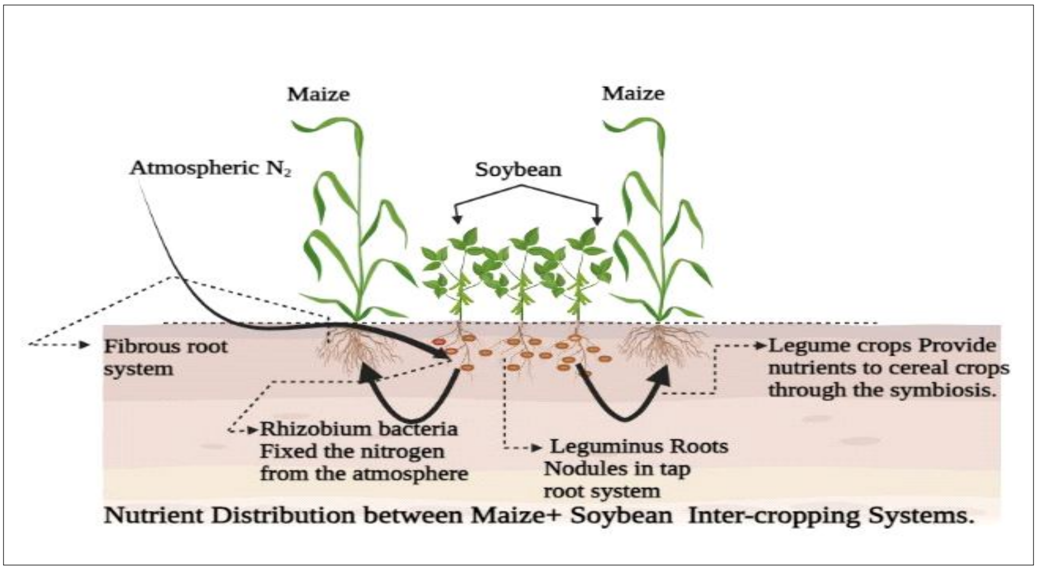

Fig 1: Nutrient distribution between legume and cereal crops in the intercropping system.

contribute more SOM, which affects soil aggregation and lowers soil bulk density. According to Ganeshamurthy *et al.* (2006), adding mung bean stover in the rice-wheat-mung bean sequence lowered bulk density and hydraulic conductivity. Gong *et al.* (2019) discovered considerably decreased BD and soil temperature under prosomillet (*Panicum miliaceum* L.) + green gram intercropping in Loess Plateau of China under loam textured soil. Intercropping potatoes with beans, peas and dolichos conserved soil moisture content by 7%, 9% and 13%, respectively, across the seasons and slope positions in comparison to the respective solo cropping systems. The inclusion of greater OM and a more extensive root system of sorghum + lablab inter-cropping systems resulted in increased hydraulic conductivity, aggregates stability, total porosity and stability index (Mathan, 1989).

Legume intercropping benefits erosion reduction by providing more dense cover against the striking impact of rainfall on the ground surface (Maitra *et al.,* 2020; Kumawat *et al.,* 2020b). Deep taproots of legumes break the hardpan and use nutrients and moisture from deeper layers of soil, whereas shallow roots near the soil surface limit soil erosion by binding soil particles (Lithourgidis *et al.,* 2011). Sharma *et al.* (2017) showed 26 and 43% lower runoff and soil loss, respectively and 13% greater yield of succeeding crop under intercropping system due to increased soil structure and moisture content. Singh *et al.* (2020) also noted 17.5% less runoff and 24% decrease in soil loss under intercropping system over sole crop.

A field study in deep Vertisol showed that, the amount of runoff was reduced by 23.7 and 19.3%, respectively when maize was intercropped with pigeon pea as well as soybeans. In comparison to the solitary maize crop, there was a reduction in soil loss, which was about 34.5 and 24.4% in the soybean + maize and maize + pigeon pea, respectively (Singh *et al.,* 2014). According to Nyawade *et al.* (2019), there was 51-70% reduction in mean cumulative sediment yield. The reduced was from 169 t ha^{-1} in sole potato plots to 50-83 t ha^{-1} in potato-legume inter-cropping.

Chemical properties of soils

Legume intercropping improves the chemical characteristics of the soil. In order to evaluate soil fertility and the sustainability of the agroecosystem, soil chemical measures such as pH, cation exchange capacity (CEC), nutrient content and SOC concentration are typically utilized (Yuvraj *et al.,* 2020). Legume crops can promote the availability of nutrients to cereals by modifying the pH of the soil in the rhizosphere. When growing legumes, the soil becomes acidic as a result of proton leakage from the roots. Proton release causes plants to accumulate organic anions, which, if recycled and decomposed in the soil, can balance out soil acidity (Meena *et al.,* 2022).

Some plants including Vicia faba utilise malate and citrate to acidify their rhizosphere when planted in phosphorus-deficient environments, thereby significantly reducing the pH of the growth media (Weidenhamer and Callaway, 2010). Pulses obtain more nitrogen as diatomic N from the air than they do as NO3 from the soil, which lowers the pH of the soil. According to Mitran *et al.* (2018), the release of organic acids from crop roots and the release of CO_2 during the decomposition of residues reduce the pH of alkaline soils.

Legumes can serve to buffer the pH of the soil by being used as an intercrop in cropping systems. As compared to a pure stand of pearl millet (Pennisetum glaucum L.), intercropping green gram with prosomillet dramatically reduced soil pH and increased SOC, total N, P and K (Gong *et al.,* 2019). The availability of N, NH4, NO3, P and K in the soil was also increased in intercropping systems (Gong *et al.,* 2019). Legumes can be used as an intercrop in a cropping system to increase SOC content in the soil, which will boost soil health (Singh *et al.,* 2025). SOC is essential for soil health. Legume and cereal intercropping increases yields per unit of land and may increase soil C-biomass compared to solitary planting (Lithourgidis *et al.,* 2011).

When compared to 21.8 g kg^{-1} of SOC in solitary maize, maize + soybean intercropping (2:3) recorded 23.6 g kg^{-1} of SOC, demonstrating the potential of legume intercropping for enhancing SOC content (Bichel *et al.,* 2016). Legumes are integrated with cereals to improve soil fertility by adding 80-350 kg N ha^{-1}, which decreases nitrogen loss by enhancing N uptake (Mobasser *et al.,* 2014). A legume crop intercropped with maize increased N uptake by 47.02% and decreased the amount of N applied per hectare from 240 kg to 180 kg (Shaoming *et al.,* 2004).

Phosphorus is the second most crucial nutrient for plants after nitrogen and is essential for the transfer of energy within plant cells. Legume crops improve the availability of P by releasing phosphatase enzymes, excreting organic acids and lowering soil pH in the rhizosphere (Varma *et al.,* 2017). However, Hinsinger (2001) noted that, the type of soil and its environmental circumstances have a significant impact on how effectively organic acids mobilize phosphorus. Both organic acids and phosphatase enzymes are excreted by lupin (Gilbert *et al.,* 1999). Gardner and Boundy (1983) found that, wheat intercropped with lupine absorbed more P due to enhanced P availability and dissolution in the calcareous soil. As a result, legume intercropping enhances the soil's chemical characteristics, including pH, CEC, SOC, the amount of total and accessible N, available P and K (Gitari *et al.,* 2019).

Organic matter in the soil beneath intercropping

Plant diversity promotes litter diversity. Litter mixing effects were commonly observed in litter diversity research because mixing litters accelerated or slowed decomposition as compared to the average breakdown of the mixture components (Hattenschwiler and Jrgensen, 2010). When the quality of litter components as a breakdown substrate varies, these behaviours are regularly observed (Meena *et al.,* 2022). Litter quantity may influence decomposition and litter quantity may be related to plant diversity, especially in the long run, due to positive interactions and feedbacks between variety, nutrient retention and production.

Several long-term biodiversity tests in grassland ecosystems have shown that species-diverse plots degrade SOM quicker than monocultures (Cong *et al.,* 2015). Intercropping is favoured over monocultures because it contains greater aboveground biomass (Lithourgidis *et al.,* 2011) and root biomass (Ghosh *et al.,* 2006). Lower C/N ratios are associated with higher breakdown rates in general (Booth *et al.,* 2005). Though there are some debates about organic matter decomposition, intercropping may improve SOM breakdown by reducing SOM reluctance cumulatively.

Microbes in the soil

Microorganisms are integral to agricultural sustainability. The rhizosphere soil of intercropped crops hosts distinct microbial communities and higher biodiversity than monocropped crops. We identified ASV6616, belonging to Nitrosomonadaceae (ammonia oxidizers), as a keystone node. Nitrosomonadaceae mostly govern nitrogen cycles by oxidizing ammonia into nitrite. Intercrop maize cultivars were linked to a unique microbial network in the maize rhizosphere, with Nitrosomonadaceae as a crucial component. The N addition in the maize rhizosphere enhances Nitrosomonadaceae abundance, fostering nitrifiers when maize is intercropped with soybean. Intercropping significantly increased nitrogen-cycling microorganisms' activity, evident even without added N fertilization (Meng *et al.,* 2015). The ability of pulses to re-fertilize soil is well proven (Bedoussac *et al.,* 2015). Grain legumes have the potential to play a key role in crop diversification/intensification in various production systems due to their inherent potential for a deep root system, biological nitrogen fixation (BNF) and, most importantly, complementarity with cereals and other non-legume crops (Meena *et al.,* 2022). According to Layek *et al.* (2018), pulses can help reverse the continuous cereal-cereal system's declining production trend by improving the soil's chemical, biological and physical environment. Soil microbes have an important role in OM decomposition, nutrient recycling, N fixation and soil structure enhancement (Ludwig *et al.,* 2015; Gong *et al.,* 2019).

Legumes as an intercrop increase soil flora and fauna diversity, resulting in more soil life stability (Begam *et al.,* 2020). By increasing root N fixing capability, legume intercropping affects root distribution pattern, structure and organic acid exudation in the rhizosphere. These changes benefit soil microbes and their interactions with crops (Singh and Chahal, 2020). Legume crops also boost microbial biomass in the soil by giving additional N via BNF. Intercropping sugarcane with green gram, cowpea and lentil raised microbial biomass corbon (MBC) by 8.1, 19.7 and 12.6%, respectively. Similarly, soil microbial biomass nitrogen (MBN) enhanced by 60.5%, 52.4% and 75.8% in sugarcane intercropped with green gram, cowpea and lentil, respectively, over sugarcane alone (Suman *et al.,* 2006).

Intercropping durum wheat with chickpea/lentil resulted in higher MBC and microbial biomass phosphorus in the rhizosphere than sole planting (Tang *et al.,* 2014). Intercropping groundnut and maize have been shown to increase the abundance of N-fixing microorganisms in the soil rhizosphere (Chen *et al.,* 2017).

Intercropping's role in nitrogen cycling and losses

Intercropping of legumes and cereals has the potential to improve N source usage efficiency due to competitive, complementing, or facilitative interactions. Several studies have revealed that competitive interactions between cereals and grain legumes result in a non-proportional distribution of soil N sources in cereal-grain legume intercrops (Jensen *et al.,* 2020).

Cereals often acquire a greater proportion of soil N than the intercrop and the grain legume compensates for its lower proportion of soil N by fixing atmospheric N2 (Naudin *et al.,* 2010). When soil N availability or fertilization

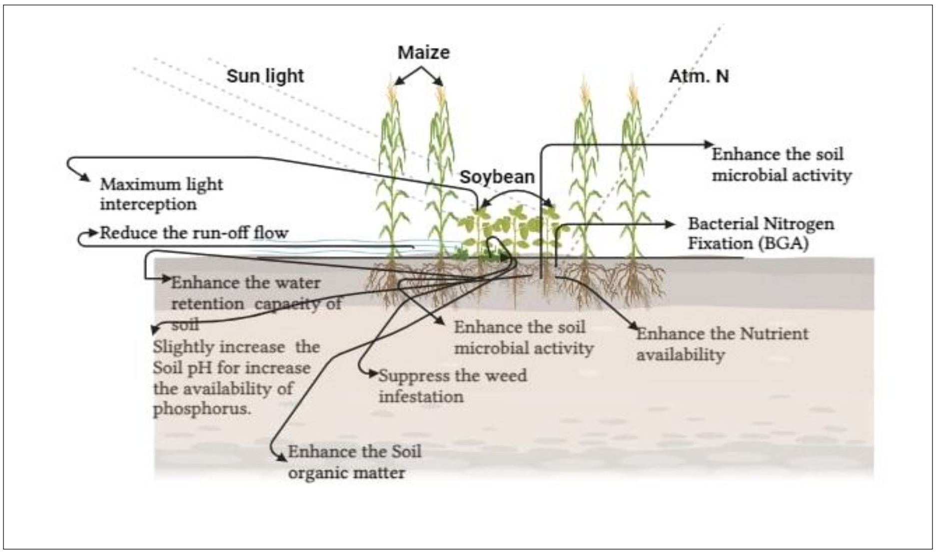

Fig 2: Plant health benefits from legume intercropping.

improves, so does the spacing between intercropped species (from mixed to strip intercropping). Because the legume will take up more soil N, the symbiotic N2 fixation will be reduced (Jensen *et al.,* 2020; Naudin *et al.,* 2010).

Intercropping gives additional benefits such as decreased (10-16%) nitrate leaching when compared to sole crops (Hauggaard-Nielsen *et al.,* 2003). Intercropping lowers N2O emissions when compared to solitary crops (Pappa *et al.,* 2011).

Constraints and problems of legumes in an intercropping system

Although legume intercropping provides numerous benefits to the agroecosystem, there are various restrictions and hurdles that hinder the widespread use of the intercropping system in modern agriculture (Stagnari *et al.,* 2017; Layek *et al.,* 2018). These limits and problems could be socioeconomic, agronomic, institutional, or environmental in nature. To popularize legume-based intercropping systems on a large area, the aforementioned obstacles must be addressed (Bationo *et al.,* 2011; Maphumo *et al.,* 2011). The following are important limits and hurdles to large-scale legume intercropping adoption (Stagnari *et al.,* 2017; Layek *et al.,* 2018; Singh and Chahal, 2020).

- Lack of quality seeds, synthetic fertilizers, biofertilizers and other farm inputs, as well as a lack of technical support and scientific knowledge about multifaceted intercropping systems in developing countries, all contribute to the system's poor performance (Layek *et al.,* 2018).
- The lack of proper farm machinery, as well as the exorbitant expense of their procurement.
- Poor market facilities, as well as a lack of financial support, infrastructure and government policies, impede the widespread adoption of intercropping systems (Maphumo *et al.,* 2011).
- The technology created by scientists at research farms with all facilities and technology implemented by resource-poor farmers differ significantly (Matusso *et al.,* 2014).
- Lack of well-developed extension services and agronomic management limits, particularly in mechanized and intensive crop production systems.
- Sometimes, legume intercropping reduced base crop yields more than pure stand yields, limiting the popularity of legume intercropping.
- The extensive canopy cover in legume intercropping may provide a microclimate conducive to the growth and reproduction of fungal diseases (Boudreau, 2013).
- Complexities of insect pests, disease and weed infestation, farmer's socioeconomic position, changing climatic circumstances, increased vulnerability of farming systems to climate change and inadequate storage facilities (Singh and Chahal, 2020).
- The susceptibility of legume crops to soil salinity and alkalinity, particularly in dry and semiarid locations (Singh and Chahal, 2020).
- Crop production is reduced in acidic soils due to lower availability of P and certain microelements (Sanchez *et al.,* 1997; Layek *et al.,* 2018).

Opportunities for legume promotion in an intercropping system

Introducing legume crops into inter-cropping systems offers a high potential for sustainable intensification of agriculture by efficiently using agricultural resources, meeting rising human requirements and enhancing the environment and soil quality (Umesh *et al.,* 2024; Ghosh *et al.,* 2016).

Promoting legumes as an intercrop in cropping systems provides critical prospects for maintaining regional and global food and nutritional security, improving the livelihood of small and marginal farmers and supporting soil health (Layek *et al.,* 2018).

Legume crops can fit into a variety of cropping systems and provide a chance to improve soil fertility and hence increase agronomic yields in intercropping systems (Ghosh, 2004). Intensive agricultural activities decrease soil fertility, hasten soil erosion, deplete SOC and result in biodiversity loss (Ladha *et al.,* 2003). Conservation agriculture (CA) is a crop production method that is designed to tackle the challenges of intensive agricultural operations while mitigating the negative effects of climate change (Kumawat *et al.,* 2020a).

Legume crops do not need fine seedbeds and can thrive in rough seedbed conditions. As a result, CA has a high potential for incorporating legume crops as intercrops into cropping systems. ZT with residue retention increased green gram yield more than CT (Kumar *et al.,* 2016). This could be attributable to enhanced microbial number and activity, as well as improved soil SOC and N (Kumawat *et al.,* 2021).

In Vertisols of Central India, Yadav *et al.* (2022) found that, retaining soybean residues under CA improves microbial activity, SOC, accessible N, P and K, moisture content and soil porosity. Raised and sunken beds, as well as modified furrow-irrigated raised beds, can provide an excellent chance to promote legumes as an intercrop by sowing them on raised beds alongside water-demanding crops like rice in sunken beds (Das *et al.,* 2014).

Due to different crop production-related constraints, roughly 22.2 million hectares of land in South Asia are left fallow after harvesting rice (Gumma *et al.,* 2016). 88% of this fallow land is available in India alone, indicating considerable possibility for grain legume introduction as relay intercropping (Kumar *et al.,* 2018). Legumes with short duration, low resource requirements and soil health restoration are the ideal crops for increasing the productivity and profitability of rice-fallow agroecosystems and giving a livelihood to millions of resource-poor small farmers (Das *et al.,* 2018).

Small-seeded legume crops such as lathyrus, lentil and others can be planted as relay inter-cropping, also known as utera or paira cropping, in rainfed lowland rice-fallow areas of India's North-East region (Das *et al.,* 2014). Das *et al.* (2018) estimated a seed yield of 400-600 kg ha^{-1} of lentil under utera farming in India's North Eastern Himalayan region. The success of relay intercropping, on the other hand, is dependent on crop selection and variety, resource conservation techniques and agronomic management approaches (Kumar *et al.,* 2016).

The incorporation of legume crops into shifting agriculture has huge potential to enhance legume-based intercropping for improving tribal groups' production and livelihood. Intercropping of grain legumes with cereals on terraces and shifting cultivation are some potential methods for popularizing legume intercropping. Grain legumes such as soybean, rice bean (Vigna umbellate L.), pigeon pea and others are intercropped with rice, maize and millets in Nagaland, India, under shifting cultivation (Das *et al.,* 2018). In the Indian Himalayan Region, legume crops are also planted alongside forest trees (alder-Alnus nepalensis) as an agroforestry system under shifting cultivation (Kumar *et al.,* 2018).

Potential future policy and action plan

The numerous advantages of legume intercropping have been extensively documented, including increased agronomic yields and net income, improved soil and plant health, reduced risks related with insect-pests, illnesses and weeds and increased RUE. Under changing climate conditions, this legume-inclusive system has enormous potential for supporting food and nutritional security as well as establishing sustainable agro habitats. However, for the effectiveness of legume intercropping systems, region-specific legumes and component crops must be developed and identified. The measurement of the N application rate in various intercropping systems is critical for increased nutrient usage efficiency and profitability.

The global popularization of legume intercropping through field demonstrations, scientific knowledge dissemination and large-scale extension efforts is critical for the livelihood security of resource-poor small landholders, as well as soil and agricultural sustainability. There is a need for knowledge dissemination concerning the long-term benefits of legume intercropping for soil and environmental security. Understanding and creating location-specific agronomic management strategies is becoming more important for the viability of intercropping systems.

Legume intercropping functions as a soil amendment, increasing soil physical, chemical and biological health, all of which must be prioritized in order to accomplish the UN's sustainability goals. CA is a sophisticated technique to sustainable agricultural production that is becoming more popular in various parts of the world. As a result, legume intercropping must be promoted under CA in order to sustain agricultural systems and ensure soil and environmental quality. Because of their low input requirements and lower frequency of insect pests, illnesses and weeds, legume intercropping should be promoted in organic farming using correct agro-techniques.

The unique potential of legume crops to fix N and recover the unavailable form of P in soil necessitates further exploration in order to reduce the usage of expensive N and P fertilizers in future crop production systems. Furthermore, advanced breeding and bioinformatics technologies are required for generating insect-pest resistant, stress-tolerant and high-yielding varieties to synchronize food demand with agricultural sustainability (Singh *et al.,* 2021; Sheoran *et al.,* 2021). The development of intercropping system-oriented farm machinery and research methodology is critical to popularizing legume intercropping among farmers. Identification of new niches for sustainable intensification and diversification of cereal-based cropping systems through legume intercropping is critical for enhancing soil and environmental benefits. To make legume intercropping more profitable, supportive policies and markets for price regulation are urgently needed.

CONCLUSION

Based on the capabilities of intercropping to increase farm income, this strategy can be used in Indian region to preserve cereal-legume production while also achieving sustainability or lowering negative environmental impacts such as soil erosion or chemical runoff. Furthermore, legume crops can be grown in a variety of cropping patterns, making them appropriate for CA organic farming systems. Intercropping legumes helps to reduce the negative impact of climate variability while also guaranteeing the livelihoods of resource-poor farmers. Thus, legume-based intercropping increases agronomic yields, profitability cropping intensification, food and nutritional security and soil sustainability.

Conflict of interest

There is no conflict of interest.

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