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Legume-based Intercropping Systems: a Promising Avenue for Sustainable Agriculture

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ABSTRACT

Legume-centric intercropping is a sustainable agricultural approach that significantly enhances soil fertility and health. This method leverages the unique properties of legumes, which are capable of fixing atmospheric nitrogen, thereby enriching the soil with this essential nutrient. Legumes contribute to improved soil quality through several mechanisms: they increase organic matter levels, enhance soil structure, and stimulate microbial activity, optimizing resource use of which are crucial for maintaining long-term soil health. This agricultural practice involves growing legumes alongside other crops, allowing for the biological fixation of nitrogen, which enriches the soil and reduces the need for synthetic fertilizers. The integration of legumes not only boosts nutrient availability but also enhances soil structure and microbial activity, leading to improved overall soil fertility. Intercropping-systems face several significant challenges that can impede research and practical application. These challenges include complexity of management, perceived risks and economic viability and limited research and knowledge. while there are notable challenges in implementing legume-based intercropping systems, their contributions to agricultural sustainability and productivity make them a valuable area for further research and development. Adopting legume-based intercropping systems is a viable pathway toward sustainable agricultural practices that enhance productivity while fostering long-term soil health and ecological integrity.

Keywords: *Intercropping, soil quality, sustainable agriculture, biological fixation of nitrogen. Legume- based, Soil fertility, ecological integrity, microbial activity, Organic matter, economic viability.*

INTRODUCTION

Pigeonpea (*Cajanus cajan* L.) is the second most important pulse crop after chickpea in India. Pigeonpea is the most important rainy season (*kharif*) grain legume crop, grown predominantly under rainfed conditions in India. It is also known as redgram, arhar or tur and is a perennial legume belongs to family Fabaceae. it is cultivated in diverse agro-climatic regions, especially in tropical and subtropical areas [1]. Pigeon pea serves as a major source of protein, energy, and essential nutrients for millions of people, particularly in developing countries. [2]. In India Pigeonpea is growing in an area of 50.02 lakh ha with production of 4.34 million tonnes and productivity of 877 kg ha^{-1}. It occupies second position in total pulse production after Bengalgram. In Telangana Pigeonpea is cultivated in 3.10 lakh ha area with the production of 237 million tones and productivity of 764 kg ha^{-1} (Indiastat, 2022-23). Studies indicate that intercropping can lead to increased overall yields compared to monoculture systems due to better resource allocation and reduced pest pressure. such soil and climatic conditions water stored in the soil and its availability to the crop is of great importance to increase and stabilize yields [4].

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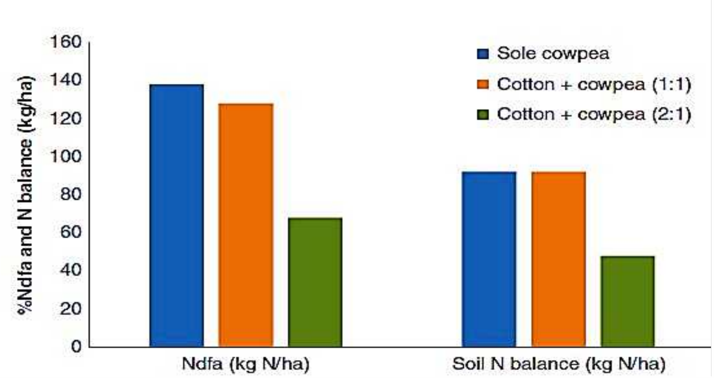
Crop intensification is in both time and space dimensions. There is intercrop competition during all part of crop growth [5]. In paired row Pigeonpea cotton intercropping system the space between the two paired rows of Pigeonpea effectively utilized for growing high density cotton. Paired row planting system allows or permits in better light interception by the crop and resource sharing for harvesting better yields [26]. the other practices to increase crops yield, intercropping is a sustainable farming practice that increases crops production by reducing the chances of crop failure owing to better use of resources such as nutrients, water and sunlight [6]; [7]. In intercropping, two or more crops are grown together and coexist for a certain period. Intercropping addresses many key problems of agricultural farming systems such as low yield, soil degradation, pest and pathogen infestation and environmental deterioration [8]; [9].

Advantages of legume based intercropping

Legumes have the unique ability to fix atmospheric nitrogen through a symbiotic relationship with rhizobia bacteria in their root nodules. This process enriches the soil with nitrogen, an essential nutrient for plant growth, thereby enhancing soil fertility. Intercropping legumes with cereals can reduce the need for synthetic fertilizers, promoting a more sustainable farming approach. [10]; [13]



Percent nitrogen derived from air (Ndfa) and N balance as affected by cotton and cowpea inter-cropping (data source: [32]

Intercropping systems often lead to higher overall productivity compared to monoculture practices. For instance, maize-legume intercropping has been shown to increase maize kernel numbers and overall yield due to improved nutrient availability and efficient resource use. The complementary nature of legumes and cereals allows for better utilization of light, water, and nutrients. [11]; [12]. Legume intercropping can help in pest and disease control by disrupting the habitat of pests that thrive in monocultures. This diversity can lead to a reduction in pest populations and lower disease incidence, contributing to healthier crops and reduced reliance on chemical pesticides [34]. Intercropping systems can improve soil structure and reduce erosion. The root systems of legumes help bind the soil, while their foliage provides ground cover that protects against runoff and erosion during heavy rains. This is particularly beneficial in regions vulnerable to soil degradation. [10];[13].

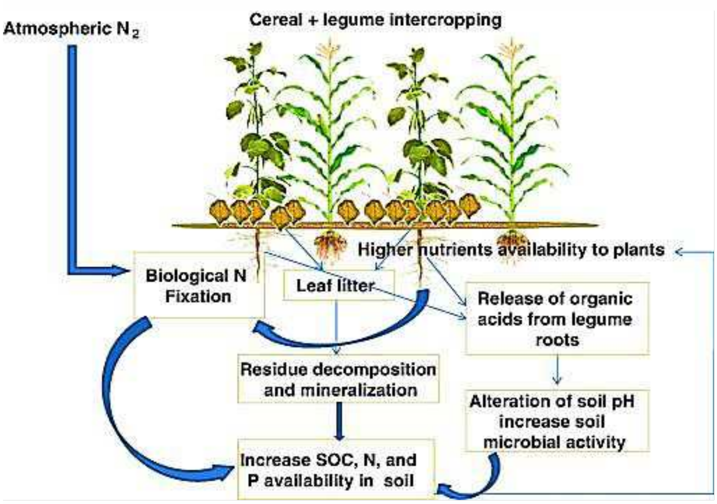


Fig. 1 Influence of legume inter-cropping on soil chemical properties. [31].

Table 1. Intercropping of legumes with other non-legume crops

Maize + cowpea-wheat intercrop combination was the most productive and economic. Legume intercropping with maize saved 25% of nitrogen in wheat crop. [33]. N2 fixation inhibition reduced by intercropping with wheat. Significant N transfer from legume to wheat increases Land Equivalent Ratio. [14].

Legume Crop	Non-Legume Crop	Benefits
Soybean	Maize	- Increased yield and land use efficiency [15] - Enhanced rhizobacterial community and nutrient uptake [30] - Improved soil properties and organic matter [16].
Cowpea	Sorghum	- Higher total productivity compared to sole cropping.[17] - Better use of growth resources and light energy - Increased yield stability
Alfalfa	Maize	- Improved water use efficiency and economic returns [18]. - Enhanced soil nutrient availability and microbial community [18].
Pigeon pea	Maize	- Increased yield and nutrient uptake [16]. - Promoted beneficial rhizobacteria under stressful conditions [30]. - Improved soil aggregation and organic phosphorus storage [30].
Field pea	Small grain	- Combine-harvested as a single crop [19]. - Legume provides nitrogen while grain adds organic matter
Hairy vetch	Rye, wheat, spelt	- Good overwintering cover crop combination [19]. - Vetch fixes nitrogen, grains provide organic matter [19].
Beans	corn	-Traditional Native American intercropping system [19]. - Usually includes squash as a third crop [19].

Agronomic practices considering for the legume based intercropping systems

1. Crop Selection: Choosing compatible legume species that complement the main crop (e.g., maize) is essential. The selection should consider growth habits, nutrient requirements, and harvest timing to minimize competition while maximizing benefits. [27]; [29]

2. Row Arrangement: The spatial arrangement of crops can significantly influence productivity. For instance, alternating rows or mixed planting can enhance light interception and resource utilization. [28]; [31].

3. Timing of Planting: Synchronizing planting times between legumes and main crops is crucial to ensure that both can benefit from shared resources without significant competition during critical growth phases [27]; [29].

4. Soil Fertility Management: Regular soil testing should guide fertilization practices tailored to the specific needs of intercropped species. Incorporating organic amendments can further enhance soil fertility and microbial activity[30]; [29].

5. Water Management: Implementing efficient irrigation strategies is vital in areas prone to drought or irregular rainfall patterns. Legumes often improve water use efficiency in intercropped systems. [27];[28].

Comparative Analysis of Yield and Sustainability Metrics in Legume-Based Intercropping Systems

Legume-based intercropping systems have gained recognition for their potential to enhance agricultural sustainability and productivity.

Yield Metrics

1. Crop Productivity: Legume intercropping can significantly increase crop yields compared to monoculture systems. For instance, a study highlighted that maize-legume intercropping achieved a land equivalent ratio (LER) of 1.71, indicating that intercropped systems can produce 71% more yield per unit area than sole cropping systems [33]. This is attributed to improved resource utilization, including light and nutrients.

2. Economic Returns: Economic advantages are evident in legume intercropping. Research indicates that combining maize with legumes can result in a net economic return increase of approximately 43.63%, with a benefit-cost ratio (B:C) of 1.94. [33]. This enhanced profitability is crucial for smallholder farmers who often operate under resource constraints.

Sustainability Metrics

1. Soil Health: Legume-based intercropping systems improve soil health by enhancing organic matter content and microbial diversity. Studies have shown that these systems can increase soil organic carbon levels by up to 79% compared to monoculture practices [33]. The promotion of beneficial rhizobacterial communities further supports soil health and resilience against stress conditions.[30]

2. Biodiversity and Ecosystem Services: Intercropping systems foster greater biodiversity, which can lead to improved pest control and reduced reliance on chemical inputs [34]. The diversification of crops not only supports ecosystem services but also mitigates risks associated with crop failure due to environmental stressors.

Challenges and limitations

Despite the benefits, the yield of pigeonpea in intercropping systems remains relatively low, often around 400-500 kg ha^{-1}. This limitation is attributed to the lack of improved cultivars specifically bred for intercropping environments [3].

Knowledge and Skill Gaps: Farmers often lack the necessary knowledge about intercropping techniques, which differs significantly from traditional monoculture practices. This gap can lead to ineffective management and reduced yields. [20]; [22].

Crop Management Complexity: Intercropping systems require more complex management strategies compared to sole cropping. This includes understanding the competitive dynamics between different crops, which can vary widely depending on the species involved and environmental conditions. [20]; [22].

Limited Breeding and Protection Development: There has been insufficient development in plant breeding and crop protection specifically tailored for intercropping systems. Most advancements have focused on sole crops, leaving intercropped varieties less optimized for pest and disease resistance. [20]; [25].

Soil-Borne Diseases: The integration of legumes into cropping systems can lead to increased risks of soil-borne diseases if not managed properly. Knowledge on how to reintegrate intercrops into crop rotations is essential to mitigate these risks. [20]; [25]

Economic Constraints: The perceived economic risks associated with intercropping, including potential yield losses and increased labor costs, deter farmers from adopting these systems. Clear demonstrations of economic viability are needed to encourage uptake. [22]; [25]

Future Directions or prospects

Expanding Research on Underutilized Crops

While much of the current research focuses on popular crops like soybeans and maize, there is a growing need to explore underutilized legumes such as lupin and buckwheat. These crops may offer unique benefits in intercropping systems and warrant further investigation into their management and compatibility with existing crops. [21].

Climate Resilience and Ecosystem Services

Legume intercropping systems can enhance resilience to climate change by improving soil health, increasing biodiversity, and providing habitat for beneficial insects. Future research should prioritize understanding these ecosystem services and how they can be maximized through strategic crop combinations. [22]. [23].

Development of Specialized Cultivars

Breeding efforts should focus on developing regional cultivars that are specifically suited for intercropping systems. This includes selecting traits that enhance complementarity between species, such as drought tolerance and pest resistance, which are crucial in varying climatic conditions. [24]; [25]

Addressing Socio-Economic Constraints

To promote the adoption of legume intercropping, it is essential to address the socio-economic barriers faced by farmers. This includes providing financial support, improving market access for legume products, and enhancing extension services to educate farmers about the benefits and management of intercropping systems. [25].

Conclusion

Legume intercropping enhances nitrogen use efficiency, significantly reducing the need for synthetic fertilizers. This not only lowers production costs but also mitigates environmental impacts associated with fertilizer use, such as greenhouse gas emissions and nutrient runoff into water bodies. These systems promote biodiversity by integrating diverse plant species, which can improve soil health, enhance pest control, and increase resilience to climate change. These systems promote biodiversity by integrating diverse plant species, which can improve soil health, enhance pest control, and increase resilience to climate change. Legume-based intercropping systems present significant advantages for sustainable agriculture, overcoming existing challenges through targeted research, farmer education, and supportive policies will be critical for their broader implementation and success.

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Future scope of the study: he future scope of legume-based intercropping systems is vast and multifaceted, encompassing environmental sustainability, economic viability, optimized crop management, technological integration, and educational outreach. Addressing these areas through targeted research will be essential for unlocking the full potential of these innovative agricultural practices in achieving sustainable food production systems.

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