Review Article

Pulses as a Key Component in Conservation Agriculture: Impacts on Soil Health and Sustainability

Abstract

Intensive agriculture poses several challenges such as soil degradation, reduced soil organic matter, and increased soil nutrient imbalances including nitrogen, phosphorus, potassium, sulfur, zinc, iron, and manganese deficiencies and nutrient toxicities [1]. It also contributes to degradation of groundwater quality, declining groundwater levels [2], and issues like sodicity and salinization [3], resulting in reduced crop productivity. Many of these limitations can be addressed by adopting conservation agriculture, which supports sustainable productivity while safeguarding natural resources [4]. Pulses are particularly beneficial in conservation agriculture as they align well with its principles: diversified crop rotations, minimum soil disturbance and continuous soil cover. They serve as a resource-conserving technology that mitigates the adverse impacts of modern agricultural practices.

Introduction

Land, a finite and precious resource, provides critical ecosystem services and supports the production of food, feed, fuel, and fibre [5]. The per capita availability of agricultural land in India is steadily declining due to the growing population, industrialization, and urbanization.

Conventional agricultural production systems rely on high external inputs posing numerous obstacles, including the deterioration of soil health, reduction in soil organic matter, and building up of nutrient imbalances in the soil. These imbalances include deficiencies in nitrogen, phosphorus, potassium, sulfur, zinc, iron, manganese, and nutrient toxicities [1]. Additionally, the over-exploitation of groundwater has led to degraded water quality and falling water tables [2]. Other issues include salinization, sodicity[3], increasing pest population and weed shift [6]. As a result, it is crucial to improve the efficiency of input utilization in crop management while preserving natural resources [7].

In response, conservation agriculture is gaining importance. The inclusion of pulses in conservation agriculture emerges as a sustainable system that addresses many concerns of modern agriculture.

Malnutrition affects nearly 200 million people due to deficiencies in dietary protein, vitamin A, and essential micronutrients such as zinc, iron, selenium, and iodine. In 2020, about 40% of the global population (3.1 billion people), faced hunger or malnutrition [8,9]. Pulses are crops rich in dietary fibre, essential amino acids, plant-based proteins, vitamins and minerals such as phosphorus, calcium, iron, zinc, potassium and magnesium [10] and have emerged as a promising crop for enhancing global food security and nutritional security.

Pulses are successfully grown in marginal and semi-marginal soils as they require minimal input for cultivation [11], making them a suitable candidate for rainfed agricultural systems which cover 83% of cultivated land. Their deep root systems and ability to resist drought make them resilient to adverse conditions. Moreover, pulses can fix atmospheric nitrogen through their root nodules, thereby decreasing the need for synthetic fertilizers, which are a major contributor to greenhouse gas emissions and environmental issues[11,12,13]. Due to these reasons, pulses are considered a climate-resilient crop. India is the major producer (29%), consumer (27%), and importer (14%) of pulses in the world [14].

Importance of Conservation Agriculture

There is increasing concern about the harmful effects of mechanization and high external input based farming methods on soil quality and environmental pollution [15]. Indiscriminate, constant and intensive tillage, along with improper crop management, degrade soil health and reduce productivity. Conventional tillage requires heavy machinery like tractors or tillers, further increasing energy demand.

Conservation agriculture (CA) offers a sustainable and resource-efficient agricultural approach. CA integrates soil, water, crop, and biological resource management to preserve and maximize natural resources. This method not only supports environmental conservation but also boosts production in a sustainable manner [16]. CA represents a technological package that saves resources and improves efficiency in agriculture, thereby reducing cultivation costs by saving labor, time, and farm power [17]. A promotes sustainable farming by increasing the efficiency of water and nutrient use. It improves nutrient balance and availability in the soil, enhances water infiltration and retention, minimizes evaporation losses, and improves both the quality and availability of groundwater and surface water [18].

Conservation Agriculture: Key Principles

1. Minimal Soil Disturbance

Tillage involves physically manipulating soil to create optimal conditions for crop germination and growth. However, it is labor-intensive, consumes significant energy and time, and accounts for approximately 30% of total production costs. The objective of minimizing soil disturbance in Conservation Agriculture (CA) is to limit tillage operations to only what is essential for seedbed preparation, germination, and crop growth while prioritizing water and soil conservation [19]. Traditionally, tillage has improved soil fertility by promoting nutrient mineralization [19]. However, excessive and prolonged tillage has led to soil erosion and the breakdown of soil structure [20]. Zero or minimal tillage reduces the negative effects of conventional tillage prevents soil erosion and improves water and soil conservation [21]. It also promotes better root zone aeration, organic matter oxidation, water infiltration, and weed seed germination [22].

2. Permanent Soil Cover

Maintaining continuous soil cover is crucial for protecting the soil from direct sun and rain in addition to produce carbon for soil microorganisms. Crop residues are key to soil cover, preventing erosion from wind and water. These residues also contribute to enhancing soil organic matter, promoting nutrient cycling, and boosting soil health [23].

3. Diversified Crop Rotations

Crop rotation is crucial for addressing both biotic and abiotic challenges formed in monoculture systems. Pulses can be added to crop rotation to minimize the damage caused by pests and diseases, promote nitrogen fixation, reduce pollution, improve soil biodiversity, and preserve soil moisture and groundwater [19,22].

PULSES: AN INTEGRAL PART OF CA

Pulses have been included in CA as an integral component. It meets all three principles of CA i.e., Minimum soil disturbance, permanent soil cover, and diverse crop rotations

I. MINIMUM SOIL DISTURBANCE

Conservation tillage

Conventional agricultural practices often rely on excessive soil tillage, which can enhance fertility initially while it deteriorates soil quality over the years. This degradation leads to structural decline, loss of organic matter, erosion, and decreased microbial diversity [15]. To minimize these problems, conservation tillage, along with suitable cropping systems, have been explored. Minimum tillage practices combined with scientific crop residue management options have been shown to decrease evaporation, soil sealing, and crusting, all of which can hinder the growth of pulse crops [24].

Chickpeas can be effectively cultivated using the residual soil moisture after harvesting rice under zero tillage conditions and covering the field with rice straw mulch [25], which resulted in a yield increase of 28% compared to traditional tillage methods under rainfed conditions. Soil moisture dynamics indicated that zero tillage combined with mulching helped to retain greater soil moisture levels during the flowering and pod-filling stages, while initial moisture depletion was higher with zero tillage. This enhanced moisture retention ultimately led to improved chickpea yields in rainfed conditions [25].

Farm Mechanization for Minimizing Soil Disturbance in Pulses

Conservation agriculture emphasizes the critical role of farm mechanization in improving land and labor productivity, particularly in the context of rising wage rates and manpower shortages. Timely and precise application of inputs demands an increased reliance on machinery.

There are machineries utilized in CA to ensure minimal soil disturbance suitable for pulse cultivation [26] and these machinery are adaptable to various ecological conditions and are environmentally sustainable. The raised bed planter improves drainage and prevents waterlogging, thereby enhancing water use efficiency by 20–30% during irrigation. The Happy Seeder, developed in collaboration between PAU, Ludhiana, and the Australian Centre for International Agricultural Research, is designed for fields with significant residue cover. It integrates a zero tillage drill and a forage harvester with inverted T-winged openers, directing the chopped material behind the drill as mulch [27]. The Turbo Happy Seeder is a lighter, advanced version with various cutting blades, adjustable row spacing, and an upgraded seed metering system [28]. The Star Wheels drill allows for direct drilling in rice fields after harvest, requiring a drill capable of penetrating untilled soil while managing large amounts of crop residue.

II PERMANENT SOIL COVER

Crop residues, the plant remains left after harvesting, play a vital role in nutrient availability, distribution, and supporting plant growth. They serve as critical sources and reservoirs of carbon (C) and nitrogen (N); they also facilitate N availability through processes of immobilization and mineralization. However, in many tropical regions, farmers often resort to burning crop residues due to a lack of awareness regarding their value and the absence of appropriate technologies for field incorporation [29]. Burning one tonne of straw emits various harmful pollutants, such as 3 kg of particulate matter, 1460 kg of carbon dioxide, 199 kg of ash, 60 kg of carbon monoxide and 2 kg of sulphur dioxide. This practice raises soil temperatures to as high as 42.2°C at a depth of 1 cm, resulting in the loss of 27-73% of nitrogen content, while also diminishing bacterial and fungal populations [30].

Pulses contribute to soil organic matter through the addition of leaf litter. For instance, long-duration pigeonpea can add approximately 2.8 t/ha of leaf litter, while chickpea contributes around 1.7 t/ha. These leaf litters supply essential nutrients, including nitrogen (8-15 kg/ha), phosphorus (2.5-5.0 kg/ha), and potassium (8-24 kg/ha). Incorporating crop residues not only supplements soil nutrients but also enhances soil structure and fertility, leading to improved productivity and better nutrient use efficiency [26].

Incorporation of mungbean residues, along with irrigation and addition of 20 kg N/ha, resulted in a 38% increase in wheat yield over the control. Residue incorporation also elevated soil organic carbon by 35.48% and increased available nitrogen (24.6%), phosphorus (11.5%), and potassium (18.5%) compared to initial soil fertility. Furthermore, incorporating residues resulted in improving the physical properties of soil, such as bulk density, pore space, and water-holding capacity [11].

III DIVERSIFIED CROP ROTATIONS

Crop diversification with pulses in conservation agriculture enhances agricultural productivity while protecting soil and environment in cereal-based rotations.More over it helps to reduce the over exploitation of groundwater and green house gas emissions. Conservation agriculture, which involves minimal soil disturbance, crop residue retention, and crop diversification, can combat soil degradation and improve food security. It provides several advantages, including increased crop yield, enhanced soil organic matter and fertility, and decreased production costs. Integrating pulses into conservation agriculture can greatly enhance the sustainability and productivity of rice-based systems, especially in areas such as Bangladesh and the Indo-Gangetic Plain [31,32]. Different methods for integrating pulses into the cropping system arediscussed below:

a) Inclusion of pulses in CA as Sequential cropping

Rice-based cropping systems play a crucial role in ensuring food security. Since the Green Revolution, rice-wheat systems have significantly expanded in the northwest, while rice-rice systems have grown in the east and south due to their high productivity and profitability with lower risks [33]. However, continuous cereal-cereal rotations in rice-based systems have reduced crop productivity and soil health in the Indo-Gangetic Plain, primarily by depleting soil organic carbon (SOC) levels [34]. Integrating pulses into cereal-based systems has proven to enhance productivity and yield components [35]. For example, the rice-wheat-mungbean system showed the highest productivity, yielding 5,140 kg/ha in chickpea equivalent, while the rice-wheat system had the lowest [25]. Similarly, long-term studies found the maize-wheat-mungbean system had the highest productivity in pigeonpea equivalent yield (3,411 kg/ha), followed by the pigeonpea-wheat system, with maize-wheat yielding the least [36].

b) Inclusion of pulses in rice follows

Utilizing summer fallows for cultivating various crops boosts overall system productivity. The choice of summer fallow crops should take into account factors such as growth characteristics, rooting patterns, crop duration, economics of cultivation and the nutrients available in the rhizosphere for the following crop. Pulse crops are well-suited for summer rice fallows, as they can fix atmospheric nitrogen [37] and improve the physical, chemical, and biological properties of soil. By adopting resource conservation practices, pulses can be efficiently grown using residual soil moisture after the rice harvest. Additionally, planting short-duration varieties during the Kharif season (between the early monsoon and dry cool season), through relay cropping or intercropping, enables better use of agricultural land that would otherwise remain fallow between seasons [38].

c) Inclusion of pulses in Mixed/ Intercropping

Mixed cropping involves cultivating two or more crops together, either by mixing seeds or planting them separately without specific row pattern. In contrast, intercropping involves planting crops in distinct rows, where sowing and harvesting can happen at the same time or at different intervals [39]. For successful intercropping, crops should differ in maturity, growth patterns, height, root systems, and susceptibility to pests, ensuring they complement each other and reduce resource competition and weather risks. Intercropping is particularly productive in rainfed areas, with over 70% of pulse cultivation in India occurring in such systems. Pulses are commonly intercropped with oilseeds, cereals, coarse grains, and commercial crops, including pigeonpea combined with short-duration grain pulses [40].

i) Intercropping with oilseeds

In rainfed areas of India, it is common to intercrop winter pulses such as chickpea and lentil with oilseeds. The most profitable combinations are lentil with mustard in the northern plains, chickpea with linseed in the central plateau, and chickpea with safflower in the peninsular region [41]. In northern India, the development of short-duration varieties that are insensitive to light and temperature has made sunflower a promising crop [42]. In Kerala, sesamum is primarily grown as a sole crop during the summer rice fallows of the Onattukara tract, using residual moisture from rice fields. Sesamum is also known to deplete soil nutrients. Incorporating leguminous crops like black gram and green gram into intercropping systems can enhance both the companion crop through nitrogen transfer and benefit the subsequent rice crop through residual effects. Among various intercropping systems, Sesamum + Blackgram in a 1:1 ratio showed the highest total productivity, monetary returns, biological efficiencies, and improvement in soil fertility [43].

ii) Intercropping with cereals

Pulses can be intercropped within rice-based cropping systems. Traditionally, chickpea was cultivated alongside wheat and barley in rainfed regions. Under water-scarce conditions, the wheat-chickpea combination was more economically beneficial compared to wheat-mustard. In irrigated conditions, wheat-mustard was found to be more profitable than wheat-chickpea [40]. Moreover, Ghosh et al. [43] reported that the rice-chickpea system yielded higher productivity compared to the rice-wheat system.

iii) Intercropping with coarse grains

Maize is cultivated during both the kharif and rabi seasons, particularly in North India and nearby hilly regions, where it is commonly intercropped with urdbean and mungbean. A suitable practice is to space one row of maize after every 2-4 rows of urdbean or mungbean. Since maize grows faster in the kharif season, planting it after 4 rows of mungbean or urdbean had shown higher equivalent yields compared to closer spacing. The maize-wheat-mungbean system, when implemented under conservation agriculture (CA) practices, achieved 38% higher productivity compared to the conventional rice-wheat system [44].

iv) Intercropping with banana

Short-duration varieties of grain cowpea, black gram, and green gram can be successfully cultivated in the interspaces immediately after planting bananas. This practice not only generates additional income but also offers benefits such as weed suppression and biological nitrogen fixation. Black gram is typically intercropped in three rows between banana rows. Because black gram matures in approximately 60-65 days, it is harvested before the banana plants fully shade the entire land [45].

vi) Intercropping with pigeonpea

Pigeonpea, due to its wide spacing, allows the cultivation of short-duration crops as intercrops. Its deep root system enables it to tap into water and nutrients from deeper soil layers, reducing competition with cereals in intercropping systems. In North and Central India, more than 90% of pigeonpea is cultivated in intercropping systems with short-duration pulses, cereals, and oilseeds, under both irrigated and rainfed conditions. Urdbean, mungbean, and cowpea are especially compatible as intercrops with pigeonpea, offering an additional yield of 400–500 kg/ha without reducing pigeonpea productivity. This intercropping practice with short-duration pulses is widely adopted in northern India [46].

d) Inclusion of pulses in CA as relay cropping

Relay cropping is a multiple-cropping method in which a new crop is planted into an existing standing crop before it is harvested. In the case of pulse with rice relay cropping, pulses are sown into a mature rice crop around 10–15 days before the monsoon begins, after which the rice is harvested. This method is considered a no-till practice and an essential part of Conservation Agriculture (CA), recognized for its benefits in improving soil health and crop productivity [47]. Replacing fallow land with pulses in the rice-fallow-pre-monsoon rice cropping cycle has been successfully implemented in various northern districts of Bangladesh, Nepal, and eastern India through on-farm trials. Integrating pulses into crop rotations via relay cropping helps intensify rice-based systems, enhancing both soil quality and crop yields [48].

e) Inclusion of pulses in CA as Catch Crop

A catch crop is a short-duration crop grown between main crops to prevent moisture and nutrient loss from the soil. It can either be harvested or incorporated into the soil to improve fertility. The development of early-maturing mungbean varieties like Samrat, Virat, Pusa Vishal, SML 668 and TMV 37 has supported their use and expansion as catch crops during the spring/summer season in the rice-wheat-pulses sequential cropping system of the Indo-Gangetic Plain (IGP) [49,40].

ADVANTAGE OF CONSERVATION AGRICULTURE WHEN PULSES AS A COMPONENT

Soil Health Improvement:

Soil Physical Properties: Improving soil physical properties through the formation of stable aggregates due to the release of glycoprotein and glomalin by pulse roots. This will increase pore space and tilth, reducing both erodibility and crusting [50]. N-rich pulse residues also encourage earthworms to create burrows, further enhancing soil structure [7].

Soil Chemical Properties: Pulses have the ability to acidify their rhizosphere by absorbing more cations than anions from the soil, which in turn lowers the pH of alkaline soils [51,52]. Pulse-based cropping systems also have the ability to improve total organic carbon [53]. The nitrogen from pulse crops accelerates the decomposition of crop residues, increasing phosphorus availability for plants [51].

Soil Biological Properties: Rhizobium bacteria in the root nodules of pulses can fix atmospheric nitrogen [54]. During this process H_2 released was oxidized by soil micro organisms and used it as an energy source to multiply rapidly, promoting plant growth [55]. The symbiotic association of pulse root with vesicular arbuscularmycorrhizal fungi helps in increasing the availability of water and nutrients to plants [56].

Nitrogen Economy

Pulses can fix nitrogen at rates of approximately 30-150 kg/ha, depending on factors such as the rhizobial population, host crop, variety, management practices, and environmental conditions. By fixing nitrogen, pulse crops can fulfil a significant portion of their own nitrogen requirements and also help to conserve nitrogen for subsequent non-pulse crops. The preceding pulse crop can add 18-70 kg/ha of nitrogen to the soil, leading to significant nitrogen savings for the following crops. In a rice-wheat rotation, cultivating mungbean in the summer can improve the nitrogen economy by 40-60 kg/ha for the subsequent rice crop [57]. Introducing pulses as a summer fallow crop helped the subsequent Virippu (Kharif) rice crop to maintain its yield even with a 50% reduction in fertilizer application [58].

Water economy

Pulses require less water compared to cereals. Globally, cereals use about 60% of the water consumed in agriculture, while pulses account for only about 4%. Pulses are efficient in water use due to their unique morphological and physiological characteristics. Their extensive root systems enable them to access moisture from deeper soil layers, allowing them to flourish even in arid conditions. The pulses require only 250 to 300 mm of water [59]. The incorporation of pulses into cereal-based systems enhances water retention capacity [26].

Cover Crop

Cover crops, which grow quickly and are primarily planted to reduce soil erosion, play a vital role in protecting the soil. Various crops differ in their effectiveness at maintaining soil cover. Various pulse crops, such as mungbean, urdbean, cowpea, ricebean, and horsegram, possess dense canopies that protect the soil surface from the impact of raindrops, effectively reducing splash erosion [61]. Additionally, pulse crops such as pigeonpea and mothbean help to reduce wind erosion. Another benefit of using pulses as cover crops is their ability to assist in weed management [60].

Nutrient Recycling

Pulses, with their deep root systems, effectively access soil nutrients from deeper layers, thereby improving the efficiency of applied fertilizers. They also help to prevent nutrient loss, particularly nitrate, from the root zone where shallow-rooted cereal crops in crop rotations may not be able to reach. The roots of pulse crops form associations with Vesicular ArbuscularMycorrhizae (VAM), which increases the accessibility of nutrients and water to the crops [62]. Furthermore, pulses add organic matter to the soil through leaf litter, root biomass, and easily decomposable crop residues. They also release organic acids into the soil, which help to mobilize nutrients that are usually not accessible.

The nitrogen-fixing ability of pulses significantly contributes to nitrogen recycling within agro-ecosystems [58]. Additionally, the root exudates and organic matter released by pulses help to convert nutrients in the soil that are not readily accessible into forms that plants can use. Thus, pulses play a crucial role in the nutrient recycling in agricultural systems [60].

Non-nitrogenous Benefits

Including pulse crops in cropping systems enhances the efficient utilization of native phosphorus. Pulse roots secrete acids that dissolve fixed or unavailable phosphorus, making it accessible to other crops in the system. For instance, chickpea can access phosphorus that is typically unavailable to other crops by acidifying the rhizosphere with citric acid root exudates in Vertisols[63]. Similarly, pigeonpea in Alfisols is known for its ability to dissolve iron-bound phosphorus [64].

Incorporating mungbeanstover into the rice-wheat system after pod harvesting significantly enhances soil phosphorus availability. This improvement is linked to the root exudates of mungbean, which help to mobilize sparingly soluble phosphorus [65]. Pigeonpea contributes 2.5-5.0 kg of phosphorus and 13.5-24.0 kg of potassium per hectare through leaf litter throughout its growth cycle[60].

Reduce Nitrate Pollution and Green House Gases (GHGs)

Groundwater contamination from nitrate leaching due to fertilizer use is a major concern in India, particularly in areas where rice and wheat are extensively cultivated. Adopting suitable cropping systems and management practices can help to reduce nitrate leaching and boost nitrogen use efficiency [66]. Pulses, which can fix atmospheric nitrogen in the range of 30-150 kg N/ha [67], leave a significant amount of nitrogen in the soil for the following crop. This can improve the nitrogen fertilizer efficiency of subsequent cereal crops by 40-80 kg/ha. As a result, pulses reduce the overall fertilizer demand for succeeding crops, thereby potentially reducing greenhouse gas emissions from fertilizer industries (Nadarajan and Kumar, 2018).

Weed suppression by pulses in CA

Weeds are a major challenge in conservation agriculture (CA) systems, and selecting appropriate crops is crucial for crop diversification to control weed invasion. Including pulses in crop rotations can be an effective strategy to keep weed populations below harmful levels. Replacing one cereal crop in a rice-based system with a pulse crop can help to reduce the weed seed bank in the soil [68]. Long-term studies in India have shown that pulse crops can reduce the prevalence of *Phalaris minor* in winter crops [69]. Additionally, fast-growing pulse crops like mungbean and black gram can compete with and suppress weed growth [70]. Several pulse crops, such as lentils and cowpea, also suppress and reduce various weeds due to their allelopathic effects [46].

Disruption of insect-pest cycles by pulses in CA

Incorporating pulses into continuous cereal-based crop rotations is highly beneficial as it helps to reduce issues with weeds, insects, and diseases. Adding pulses to the rotation enhances soil structure, decreases insect and disease occurrences, and promotes mycorrhizal colonization (Wani et al., 1995). In the rice-wheat cropping system, the inclusion of pulses significantly lowered the population of *Phalaris minor* and the incidence of diseases and pests in a long-term experiment conducted in Kanpur [46,67].

Constraints in the adoption of conservation agriculture

The major constraints that prevent the widespread adoption of CA are:

- The lack of suitable seeders, particularly for small and medium-scale farmers, continues to be a significant challenge. Although efforts have been made to design and promote seeding equipment, especially for no-till farming, its widespread adoption has been slow. There is still a need for machinery that can accommodate diverse crops and cropping sequences.
- Another challenge lies in the widespread use of crop residues for livestock feed and fuel, especially in rainfed regions. Farmers often face a shortage of these valuable residues due to lower biomass production, which creates a conflict between using them for conservation agriculture (CA) practices or for feeding livestock. This competition presents a significant obstacle to advancing CA in these areas, as farmers struggle to balance their immediate needs with long-term agricultural sustainability. To promote CA more effectively, innovative solutions will be needed to address this resource competition and support farmers in maintaining both livestock care and sustainable farming practices.
- In addition, the burning of crop residues has become widespread, particularly in the rice-wheat farming systems of northern India. Farmers resort to this practice to ensure timely sowing of the next crop due to the lack of appropriate machinery for conservation agriculture (CA) systems. This practice, however, contributes to environmental issues in the region.
- Furthermore, there is limited awareness among policymakers, agricultural leaders, extension workers, and farmers about the potential benefits of conservation agriculture (CA). The various CA practices, including planting, harvesting, water and nutrient management, as well as pest and disease control, need more scientific evaluation and adaptation to meet the demands of evolving farming systems.
- Lastly, there is a significant shortage of skilled personnel and scientific experts capable of effectively managing conservation agriculture (CA) systems. Overcoming these challenges will require a concerted effort to build the capacity of scientists, enabling them to adopt a systems-based approach to CA. This includes fostering close collaboration with farmers, extension workers, and other key stakeholders to ensure that CA practices are successfully implemented and adapted to local conditions. Training and equipping these professionals with the necessary knowledge and tools is essential for the long-term success and sustainability of CA. [72].

Possibility in Kerala

Rice is being cultivated in an area of 205040.46 ha in Kerala [73] and most of these are being kept fallow during the summer season. Pulses are the best choice of farmers for summer rice fallows as the third crop, as the crop can perform well under residual moisture and under conservation agriculture. In recent years, due to unpredictable heavy monsoons, delay occurred in the harvesting of the second crop of rice. This leads to delay in the tillage operations and sowing of pulses, which results in lower germination rate and crop stand due to the loss of residual moisture. Conservation agriculture (CA) practices that incorporate pulses as a key component have proven effective in reducing production costs, saving time, lowering carbon emissions, and enhancing soil health. To increase public awareness of the nutritional advantages of pulses and their significance in sustainable food production, contributing to food security and better nutrition, the 68th UN General Assembly proclaimed 2016 as the International Year of Pulses (IYP). In the same year, ICAR approved cluster frontline demonstrations on pulses under the NFSM scheme, which were carried out across India through KrishiVigyanKendras. The programme was implemented in various districts of Kerala viz., Kollam, Pathanamthitta, Malappuram, Kottayam, Kannur, Palakkadu and Wayanadu (more than 100 ha) continuously for 5 years comprising frontline demonstrations on green gram, black gram and grain cowpea. In Kollam district, the program was mainly implemented in summer rice fallows with minimum tillage. KVK Kollam implemented a project titled "Establishment of Protein Park in the Rice Growing Tracts of Kollam District with Special Emphasis on Soil Health" across selected panchayats. The initiative aimed to promote the sustainability of the rice-rice-pulse cropping system, highlighting the importance of pulse cultivation. The project's primary goals were to ensure food, nutritional, and soil health security, as well as conserve soil moisture through integrated crop management with a focus on safe farming practices. Funded by the Government of Kerala (GoK), this initiative led to increased pulse production. Additionally, the Kendra established a pulse processing facility as part of the project. The promotion of pulses as an intercrop in crops like banana, tapioca, and coconut during its initial growth stages was also successfully demonstrated under the project.

Future Directions for Research and Action:

- Efforts should focus on identifying post-emergence herbicides, effective for controlling weed in pulse crops under CA systems.
- Research is needed to develop genotypes that are tolerant to post-emergence herbicides.
- Initiatives should aim at developing crop varieties that are suitable for diversification within conservation agriculture systems.
- Varieties with vigorous root systems and early growth that provide rapid ground cover should be developed for cultivation under CA practices. Super-early varieties can be successfully grown during the rice fallow periods.
- There is a pressing need to develop legume varieties that can play a crucial role in enhancing the restoration of soil organic carbon (SOC). Legumes are known for their ability to fix nitrogen, but by creating varieties specifically designed to improve SOC levels, they could contribute even more to soil health and fertility. These improved legumes would not only support carbon sequestration efforts but also enhance soil structure, water retention, and nutrient cycling, making them an essential tool in promoting sustainable agriculture and mitigating climate change impacts.
- Development and deployment of legume varieties that are tolerant to abiotic stresses such as waterlogging, cold, heat, drought, and salinity are critical for mitigating the impacts of climate change.
- Assessment of greenhouse gas emissions from pulses within rice-based systems under CA is essential to identify alternative methods for reducing greenhouse gas emissions compared to existing cultivation practices.

- Further research is necessary to enhance nitrogen fixation by developing more effective rhizobium strains and improved inoculation methods. As nitrogen fixation is influenced by fertilizer application, more resilient rhizobium cultures are needed. Additionally, research should focus on a nutrient management system that complements nitrogen fixation, as legumes alone may not meet nutrient requirements. Investigating the combination of mineral fertilizers with rhizobium inoculation to create an optimal nutrition system is also critical. The extent to which legumes can fix atmospheric nitrogen and contribute to soil nitrogen levels should be quantified.
- Efforts should be made to promote farm machinery suitable for CA through demonstrations, as this will reduce cultivation costs, save time, and attract rural youth.
- Developing pulse varieties that are suitable for machine harvesting can encourage large-scale commercial pulse cultivation, moving away from subsistence farming practices.

Conclusion

The extreme exploitation of natural resources is a concern that threatens the health of ecosystems and global food security. As a result, sustainable agricultural production systems that emphasize conserving natural resources are becoming popular nowadays. Conservation agriculture (CA) systems focus on preserving, enhancing, and efficiently using natural resources by combining the management of soil, water, and biological resources while minimizing the use of external inputs. Pulses are ideal for crop diversification in CA, as they offer numerous benefits, like improving soil health, maintaining natural resources, mitigating and adapting to climate change, and promoting economic stability. As a result, pulses play an important role in conservation agriculture, and incorporating them into crop rotations supports the three core principles of CA.

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