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Review paper

Pulses in conservation agriculture: An approach for sustainable crop production and soil health

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ABSTRACT

Conservation Agriculture (CA) has emerged as a pivotal paradigm in modern agriculture, emphasizing sustainable practices to enhance crop productivity while preserving soil health and natural resources. Conservation agriculture relies on three key principles: including minimum soil disturbances, permanent soil covers with crop residue and promoting crop/species diversification. Pulses possess unique attributes, such as biological nitrogen fixation, leaf litter fall, nutrient-enriched crop residues, and a deep root system with enhanced rhizospheric activities, which make them conducive to CA principles. In the agriculture systems of southern Asia, the continuous practice of conventional input-intensive cereal-dominated production has largely contributed to soil degradation, depletion of underground water resources, and reduced land and water productivity, ultimately jeopardizing sustainable food production. Given this, researchers emphasize the pivotal role of crop diversification including pulses in the system in order to conserve natural resources, foster soil health, and sustain crop productivity. Experimental findings from diverse agro-ecologies provide evidence that the integration of pulses in CA not only contributes to enhanced agricultural sustainability but also holds the potential to address food security and nutrition challenges in an era marked by climate uncertainties and environmental degradation. Given the growing significance of pulses in CA, there is a pressing need for more systematic studies across diverse agro-regions to maximize the benefits of CA. This article highlights the important role of pulses in CA, focusing on its potential benefits pertaining to sustainable crop production, resource conservation and soil health.

Key words: Biological N Fixation, Crop productivity, Nutrient recycling, Profitability, Resource use efficiency, Soil health

INTRODUCTION

Pulses play a crucial role as a dietary component and are essential for ensuring food and nutritional security worldwide. Pulses are largely cultivated under rainfed conditions where soil moisture is the critical factor determining the productivity. The conventional agriculture approach, characterized by repeated tillage operation, intensive fertilizer application, water use and crop residue removal, has indeed increased crop productivity over the last century (Godfray *et al.*, 2010). However, this intensive use of the synthetic fertilizers and pesticides in conventional agricultural practice(s) have been responsible for degrading soil quality, depleting natural resources and facilitated biodiversity losses (Foley *et al.*, 2011). On the contrary, Conservation Agriculture (CA) adheres to the principles of minimum soil disturbances, permanent soil covers of crop residue or cover crops and crop rotations (Pittelkow *et al.*, 2015), which is often promoted as an environment-friendly alternative to the conventional agriculture system (Knapp *et al.*, 2018). No-tillage (NT), a central component of CA, stands out as the most cost-effective approach to safeguard and rehabilitate soil resources (Buffett *et al.*, 2012). Soil fertility in conventional tillage practices is reported to improve microbial activity and a reduction in erosion due to the simultaneous decline in the requirement of synthetic fertilizers and, thus, circuitously protect the environment from radiative forces through the sequestration of carbon and nitrogen (Briones and Schmidt, 2017). NT also requires lower inputs and had slightly lower or even comparable yields than the conventional tillage system (Pittelkow *et al.*, 2015). CA has consistently demonstrated its capacity to increase crop yield (Farooq *et al.*, 2011; Bhushan *et al.*, 2007), improve soil organic matter and fertility, improve nutrient cycling and plant uptake (Kaschuk *et al.*, 2010), augment soil moisture (Unger *et al.*, 1991; Saha and Ghosh 2013), and reduced production cost while maintaining, or even increasing crop yields (Bell *et al.*, 2019).

Crop diversification with pulse crops in CA emerges as an efficient strategy to increase crop productivity while protecting soil and the environment. The introduction of pulse crops into cereal-based rotations enhances system productivity in long run (Ghosh *et al.*, 2020). In Indian context, where pulses are predominantly rainfed crops, the promotion of pulse-based rotations with lower input requirements serves as a means to curtail excessive groundwater use as well as reduce production costs. The inclusion of pulses in CA offer a range of potential benefits, including improved soil health and soil aggregation (Bhattacharyya *et al.*, 2009), which would lead to their residual effects on the subsequent crops. Pulse crops, in general, fix 40-150 kg of atmospheric N per hectare through microbial associations. Inclusion of pulses in cropping system also enhances the microbial activities (Nadarajan and Kumar, 2018). Thus, pulses in CA are a vital approach to reverse the detrimental effect of conventional rice-based systems and contribute to achieving the twin goals of enhancing crop productivity and sustainability of rice-based systems and soil health. The review paper deals with the role of pulses in CA for sustainable crop production and soil health. Therefore, the inclusion of pulses in CA is a vital approach to counteract the adverse effects of conventional practices, promoting both crop productivity and soil health. This review underscores the importance of pulses in CA for achieving sustainable crop production and maintaining soil health.

ROLE OF PULSES IN CONSERVATION AGRICULTURE

Pulses have the unique ability to trap atmospheric N in their root nodules in association with a bacterium called *Rhizobium*. Besides this pulse crops add significant amount of organic matter to soil and protect from soil erosion. Pulses fitted well in all three principles of CA (minimum soil disturbances, soil covers of crop residue and crop diversification) to achieve objectives of CA. Therefore, inclusion of pulses in cereal-based crop rotation could be an effective approach for improve crop productivity and soil health that will reverse the negative effect of cereal- cereal rotation systems.

Pulses for improving crop productivity and profitability in CA

Degradation of natural resources is a serious environmental problem that threatens ecosystem health and food security worldwide. The declining yield and factor productivity observed in major cereal-based cropping systems over the past two decades, particularly in the Indo-Gangetic Plains (IGP), have prompted researchers and farmers to seek alternative crops that can simultaneously address declining productivity and ensure system sustainability. This has forced the researchers and farmers to look for an alternative crop, which can solve dual problems of declining factor productivity and system sustainability. Due to the intrinsic nature of fixation of atmospheric N, pulses improve the soil health and can be fitted well under such situations in cereal-based systems. The lower cost of cultivation and higher market price resulted in higher system productivity and profitability from the pulse-based cropping system in comparison to the cereal-based system. CA aims to conserve, improve, and make most efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs.

In a long-term study at ICAR-IIPR, Kanpur revealed that inclusion of pulses in the cereal-based system increased system productivity as well as yield component of crops. Highest system productivity in terms of chickpea equivalent yield was recorded in rice-wheat-mungbean followed by rice-chickpea and lowest under rice-wheat cropping system. In another long-term study revealed that the highest system productivity in terms of pigeonpea equivalent yield was recorded in maize-wheat-mungbean followed by pigeonpea-wheat and least under maize-wheat cropping system. However, field experiment on resource conservation revealed that rice-chickpea-mungbean and rice-chickpea performed better than rice-wheat system in terms of productivity, economics, and sustainability (IIPR, Annual report 2012-13). Similar results were also reported by Ghosh *et al.* (2012) and Ali and Kumar (2006). Higher yield of pulses after rainy season rice with reduced tillage was also reported by Pratibha *et al.* (1996) and Mahata *et al.* (1992) from the rainfed areas of eastern India.

Growing short-duration pulses (60-75 days) as intercrop also play a significant role in enhancing total productivity per unit area. Intercropping of mungbean and urdbean is most popular among farmers in IGP of South Asia while intercropping of winter pulses like chickpea and lentil with oilseeds is common in rainfed areas. Higher productivity and monetary returns can be obtained from chickpea + mustard, lentil + linseed, and wheat + lentil intercropping systems (Ali and Mishra, 1996; Singh and Rathi, 2003). Kumar *et al.* (2010a) demonstrated that the horsegram can be also intercropped with early pigeonpea and maize in mid hills of Himalaya. Many other intercropping systems were also reported by several workers (Ahlawat *et al.*, 2005; Kumar *et al.*, 2006, 2008, and 2010a, b). Studies have demonstrated synergistic effects of urdbean and mungbean on sugarcane yields in spring-planted crops, resulting in an additional yield of 0.4-0.5 tonnes per hectare for these pulses (Lal *et al.*, 1999; Varma and Meena, 2016).

Higher yield of lentil after wet season (rainy season) rice and with conservation tillage was also reported by Bandyopadhyay et al. (2016) under rainfed areas of eastern India. This approach can significantly reduce cultivation costs through labor, time, and farm power savings and improve input-use efficiency. Several researchers also reported substantial savings of energy and labour costs in CA)-based management technologies, while improving the quality of soil and the environment (Jat *et al.*, 2015; Sapkota *et al.*, 2014). A five-year field experiment conducted by Kumar *et al.* (2018) revealed that CA-based rice-wheat-mungbean systems improved the system productivity by 11% and profitability by 24% compared to conventional rice-wheat system/farmers practice (12.3 Mg ha^{-1} and INR 85,800 ha^{-1}, respectively). However, adoption of zero tillage without surface residue mulch usually results in lower yields (Verhulst *et al.*, 2011; Baudron *et al.*, 2012; Thierfelder *et al.*, 2013; Yadvinder *et al.*, 2014) compared with conventional tillage. Jat *et al.* (2018b) reported that CA-based maize-wheat-mungbean system on permanent beds improved the system productivity by 38% and profitability 84% over conventional rice-wheat system. They also reported that CA based maize-wheat-mungbean system enhanced the system productivity by 28–30% and net returns by 37–41% on permanent beds compared to their conventional tillage practices. CA-based maize-wheat-mungbean systems increased the productivity by ~15% and profitability by ~50% compared to conventional farmers' practice (Kumar *et al.*, 2018; Jat *et al.*, 2019d). On an average, the inclusion of mungbean in cereal systems (rice-wheat/maize-wheat) contributed 18% to system productivity and 15% to total net returns (Choudhary *et al.*, 2018a). Sustainable intensification of the conventional rice-wheat system with CA-based rice-wheat-mungbean improved the system productivity by 11%, profitability by 24% using 28% less irrigation water, and 25% less energy input (Kumar *et al.*, 2018; Sharma *et al.*, 2019). The inclusion of pulses in cropping systems has emerged as a promising strategy to combat declining productivity and promote sustainability, offering substantial benefits such as enhanced soil health and reduced reliance on inputs like irrigation water and energy. These research findings underscore the importance of incorporating pulses and sustainable agricultural practices into farming systems to address the complex challenges facing agriculture today.

PULSES IN CA FOR IMPROVING SOIL HEALTH

Soil physical properties

Pulses, when integrated into conservation agriculture practices, play a crucial role in enhancing soil physical, chemical, and biological properties. Pulses under CA practices helped in improving the soil physical, chemical, and biological properties. Degradation of soil structure and aggregation due to intensive tillage, non-recycling of crop residue to soil systems, and monoculture systems have contributed to low infiltration rate resulting in reduced soil hydraulic conductivity, decreased groundwater recharge, and consequently severe depletion of groundwater in many intensively irrigated agro-ecosystems (Humphreys *et al.*, 2010; Bhatt *et al.*, 2016; Kumar *et al.*, 2019). The inclusion of pulses in the cereal-based system offers a promising solution for improving soil quality. The bulk density, porosity, infiltration and other physical parameters were improved under rice-lentil, pigeonpea-wheat, and rice-wheat-mungbean. Kumar *et al.* (2016) reported that conservation tillage with proper crop residue management reduce soil water evaporation, soil sealing, and crusting. Notably, hydraulic conductivity in the presence of straw retained with NT was significantly higher than that in conventional tillage.

Wilhelm *et al.* (2004) revealed that the significance of soil organic matter (SOM) in enhancing soil productivity and sustainability is notable. Pulse crops can enhance SOM, which balance out soil aggregates, make the soil easily cultivable, and increase air circulation, soil water holding, and buffering limits. Furthermore, the breakdown of SOM provides accessible nutrients to plants. It also physically and chemically binds primary soil particles within aggregates thereby increasing the stability of the aggregates and prevents their breakdown during wetting procedure (Lado and BenHui, 2004). According to Tisdall and Oades (1982), roots and hyphae are the major binding agents for macroaggregates (>0.25 mm), while humic compounds promote microaggregate (<0.25 mm) formation. Crop rotations that include pulse crops are generally beneficial to aggregate stability and formation of a favorable soil structure. The fungi present in the legume crop rhizosphere produce a glycoprotein called "glomalin." This sticky substance entraps soil mineral, organic matter, and debris to form stable soil aggregates. Hence, the microbial activity of rhizosphere is directly responsible for the improved soil structure in crop rotations involving grain legumes. Ganeshamurthy *et al*. (2006) reported that inclusion of mungbean in rice-wheat system resulted in lower bulk density and improve hydraulic conductivity. The improvement in overall soil physical parameters with grain legume inclusive cropping systems have been documented in two sets of long-term study in sandy loam (*Typic Ustochrept*) soil of the IGP (Kumar *et al*., 2012).

Soil chemical properties

Pulse crops have both direct and indirect effect on soil chemical properties i.e. pH, nutrient accessibility, exchange capacity, etc. They possess the ability to reduce the pH of soil in the rhizosphere and make microenvironment favorable for nutrient availability. As grain legumes acquire a greater part of their N requirement from the air as diatomic N rather than from the soil as NO_3, their net effect lowers the pH of the soil. Among grain legumes, chickpea exhibits the most significant pH reduction, followed by pea and pigeonpea (Singh *et al*., 2009). Grain legume crops contribute a substantial amount of organic residues to the soil in the form of root biomass and leaf litter. Roots and leaf litters being rich in N facilitate fast decomposition of crop residues in soil and increase microbial activity (Singh *et al*., 2009). Inclusion of legume in cropping system not only economizes the N requirement of cropping system but also facilitates in the efficient utilization of native phosphorus (P) due to secretion of low molecular weight aliphatic acids that help in solubilization of various forms of P. This capacity of the legumes makes them efficient in native utilization of P present in different forms. Increased availability of P is a result of P acquisition from insoluble phosphates through root exudates. Chickpea has the ability to access P normally which is not available to other crops by mobilizing sparingly soluble Ca-P by acidification of rhizosphere through its citric acid root exudates in Vertisols, and pigeonpea have been characterized for dissolution of Fe-P in Alfisol (Ae *et al*., 1991). Pulses or food legumes due to their ability in atmospheric N fixation, leaf shedding ability and higher below ground biomass add significant amount of organic carbon to soil (Ganeshamurthy, 2009). Singh and Sandhu (1980) and Newaj and Yadav (1994) also reported an increase in organic carbon content over the initial level as a result of including pulses in cereal based cropping systems.

Rice- wheat cropping system is highly nutrient exhaustive and therefore, its continuous practice has depleted inherent soil fertility, causing deficiencies of several nutrients (Zia *et al*., 1997). Observations were recorded in two long-term trials at ICAR-IIPR, Kanpur in which SOC improvement was recorded in rice-chickpea, rice-wheat-mungbean in lowland situation and maize-chickpea, pigeonpea-wheat and maize-wheat-mungbean system in comparison to rice-wheat and maize-wheat, respectively. Inclusion of pulses in rice-wheat and maize-wheat cropping systems also increased different fractions of soil organic carbon. Inclusion of a single pulse crop like summer mungbean in rice-wheat and maize-wheat systems improved the total organic carbon content, being greater in surface soil (0-0.2 m) depth. CA-based rice/maize-wheat-mungbean increased soil organic carbon by 65–70% and available N, P, K by 50, 30, 45%, respectively over conventional rice-wheat system after 4 years of cultivation (Jat *et al*., 2018a). Additionally, adopting CA-based rice/maize-wheat-mungbean systems allowed for a 30% reduction in N and a 50% reduction in K dosage while maintaining the same yield levels. CA-based rice/maize-wheat-mungbean system increased the total organic carbon (TOC) by 77.5% compared to farmers' practice after 6 years of experimentation. Venkatesh et al. (2013) reported that the relative efficiency in SOC management, the crop rotation was found in the order of maize-wheat-mungbean > pigeonpea-wheat > maize-wheat-maize-chickpea > maize-wheat.

Soil biological properties

Diversity of soil flora and fauna also increased due to pulses leading a greater stability to the total life of soil. Living soil organisms play a significant role in agroecological sustainability, influencing several soil properties and processes that directly or indirectly affect crop yields. Recognizing the importance of soil microorganisms for agroecological sustainability and crop productivity, soil biological parameters are now considered essential indicators for assessing soil health. Pulses offer favorable conditions for the growth and development of soil microorganisms. The soil microbial biomass is the living portion of the soil that includes microorganisms and parasites, including soil microfauna and green growth (Kumar and Goh, 2000). Pulses can act as soil fertility restorers in cropping system due to their ability to fix atmospheric N in symbiosis with Rhizobium. The association of pulse crops roots with vesicular arbuscular mycorrhizal (VAM) helps in increasing availability of nutrients and water to crop plants. The symbiotic association of *Rhizobium* and arbuscular mycorrhizal (AM) with roots of pulses increases N and P availability in soil for plant use. This is attributed due to fixation of atmospheric N by root nodulating *Rhizobium* bacteria and through enzymatic activities of the AM fungi. The rhizobacteria help in fixing nitrogen whereas many fungi like VAM can function to convert insoluble phosphates to soluble forms, accumulate plant nutrients, and reduce the severity of plant pathogenic diseases (Mohammadi and Sohrabi, 2012). Pulse crops enhance hydrolytic enzymes including dehydrogenase, urease, protease, phosphatase, and β-glucosidase activities in the soil. Long-term studies conducted by Venkatesh *et al*. (2013) and Dhakal *et al*. (2015) revealed that inclusion of pulses in rice-wheat and maize-wheat systems has shown altogether enhanced soil biological properties.

Pulses improve physical (soil aggregates, pore space, bulk density), chemical (organic carbon, pH) and biological properties (soil biota population, efficiency and synergy, microbial biomass carbon) of soil (Ali and Venkatesh, 2009). Inclusion of a short duration pulse crop in the rice-wheat system is beneficial to break the monotony of cereal-based systems and to improve the soil quality (Gathala *et al.*, 2013; Jat *et al.*, 2018a). CA-based maize-wheat system recorded the highest soil quality index (SQI) of 1.45, whereas 0.58 with CA-based rice-wheat system and the lowest score (0.29) in conventional rice-wheat system (Choudhary *et al.*, 2018b). Mungbean integration in CA-based maize-wheat system showed higher SQI (0.76) than other rice-wheat systems (Choudhary *et al.*, 2018c). Thus, pulses play a pivotal role in enhancing soil health and agroecological sustainability by promoting the diversity of soil flora and fauna. This increased diversity contributes to greater stability in the soil ecosystem, benefiting crop yields.

Biological N fixation and nutrient recycling

Pulses have been integral to agriculture for centuries, serving as a vital N source globally. After carbon and water, N is the most imperative constraining elements for the development of plant and yield of crops (Vance, 1997; Peoples *et al*., 1995). A portion of the N fixed by leguminous crops benefits the subsequent crop, reducing the need for N fertilizer in the following crop (Reeves, 1994). Pulses fix 30-150 kg N ha^{-1} depending upon the rhizobial population, host crop, management level, and ecological conditions. The N fixation amount by pulses is quantified largely by the hereditary capability of the crops and by plant accessible N rate in the soil. Rhizobium is a fast-growing, acid-releasing microbe, while Bradyrhizobium is a slow grower that does not acidify the soil (Brady and Weil, 2002). The amount of N released by the leguminous crops in the soil is adequate to make desired yield level of succeeding non-leguminous crops; while higher N requiring crop, for instance, the corn, largely need supplemental N. Frye *et al*. (1988) suggested in such crops, N rates could be cut down evidently while keeping up the expected crop yields. Moreover, Peoples *et al*. (1995) reported that in agriculture systems about 90 to 140 Tg N year^{-1} is supplied through biological N fixation (BNF).

Pulse crops contribute organic matter to the soil through leaf fall, root biomass, and easily degradable crop residue. Pulses also release organic acids in soil, thereby mobilizing un-available soil nutrients. The ability of pulses to fix atmospheric nitrogen plays a great role in N- recycling in agro-ecosystem. Similarly, the root exudates released by pulses and the organic matter added to the soil make unavailable soil nutrients in plant available forms. Therefore, pulses play a significant role in nutrient recycling (Nadarajan and Kumar, 2018). This multifaceted contribution underscores the importance of pulses in sustainable agriculture and the efficient use of resources.

Pulses in CA and resource use efficiency

Inclusion of pulses in cropping system and adoption of CA-based management practices has tremendous potential to tackle the problems of falling ground water, nutrient and energy use efficiencies. CA-based rice-wheat-mungbean systems increased the water productivity by 58%

(0.74 kg grain m^{-3}) while using less irrigation water (28%) and energy input (25%) (59.6 GJ ha^{-1}) over conventional rice-wheat system. On 3 years basis, CA-based maize-wheat-mungbean system on permanent beds saved 83% of irrigation water over conventional rice-wheat system (2005 mm ha^{-1}) while enhancing water productivity by 24.5% (1.52 kg grain m^{-3} water) over conventional rice-wheat and by 24.3% (1.13 kg grain m^{-3} water) over maize-wheat system (Jat *et al.*, 2018c). Nutrient Expert® based SSNM in CA-based maize-wheat-mungbean system increased the crop productivity, water use efficiency, and net returns by ~13% (3 yrs' mean) compared to farmers' fertilizer practice (Jat *et al.*, 2018c). CA-based cereal (rice/ maize) systems recorded higher net energy of 251% compared with those of the CT-based cereal system (295,217 MJ ha^{-1}), irrespective of mungbean integration (Jat *et al.*, 2020a). Incorporating pulses into cropping systems and adopting CA management practices offer a compelling solution to address declining groundwater levels, inefficiencies in nutrient and energy utilization. These results underscore the substantial potential of CA practices to not only mitigate resource challenges but also improve agricultural sustainability and economic outcomes.

CONCLUSIONS

Pulses are suitable crops for crop diversification in CA for sustainable crop production in cereal-based cropping systems. Pulses are climate-hardy crops and adapt to climate change effects, improve soil health by supplying nutrition and help to maintain natural resources. With limited scope for further expansion of cultivable area, production can be increased through CA-based intensification of agriculture by increasing cropping intensity per unit of land and increasing yields per hectare with inclusion of pulses in cropping system. The CA-based cropping system not only conserves natural resources but also helps in reducing the cost of cultivation, improves soil health, promotes timely planting and ensures crop diversification, reduces environmental pollution and adverse effects of climate change. Inclusion of pulses to fit into various cereal-based cropping systems can be crucial to increase resilience to climate change and improving soil health, crop productivity, and sustainability. Hence, the addition of legume crops in CA for the cereal-based system may be an excellent option to sustain the natural resources and to maintain the production sustainability, farm profitability, and soil health. Integrating pulses into CA systems not only improves agricultural sustainability but also addresses broader environmental and economic concerns in agriculture. Despite of the increased significance of pulses in CA, systematic exploration and adoption of pulse-centric CA practices is needed to ensure resilient and sustainable agricultural systems.

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