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Conservation Agriculture for Sustainable Agriculture

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

The paper is centered on the concept of conservation agriculture (CA), which is defined as a sustainable cultivation system for the future. Conservation agriculture (CA) is a sustainable farming system that promotes minimal soil disturbance, permanent soil cover, and crop rotations to maintain soil health and productivity. This approach focuses on maximizing natural resources, reducing inputs, and improving the efficiency of nutrient use. CA practices have been found to reduce soil erosion, conserve water, and increase soil organic matter, leading to improved crop yields and reduced greenhouse gas emissions. In addition to improving agricultural productivity, CA can also contribute to broader sustainable development goals, including poverty reduction, food security, and biodiversity conservation. However, the adoption of CA requires a shift in mindset and significant investment in equipment, training, and research. Conservation agriculture (CA) started in 1930 and it didn't gain popularity till 1950. But from 1950 to 1990, there was very little rise- CA was practiced in only 2-million-hectare land. From 1990 to 2015, CA was practices in almost 180-

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million-hectare land with 10-million hectare annually around the world. The places where CA is practiced the most is Brazil, next is America followed by Australia. In India, CA is practiced at 3-million-hectare land in different forms. Various types of machinery and techniques are used in conservation agriculture such as zero tillage, crop diversification and intensification, multi crop zero tillage plant, mechanical transplanter, happy seeder and laser land leveler. The use of machinery in CA has several benefits, including improved soil health, increased crop yields, and reduced labor and input costs. However, the adoption of CA machinery requires significant investment in equipment and training, and there may be limitations in some regions due to soil conditions and crop types. However, promoting CA technologies still faces challenges such as the lack of appropriate seeders for small-scale farmers, competition between CA use and livestock feeding for crop residues, burning of crop residues, a shortage of skilled manpower, and overcoming the traditional mindset about tillage. Drawback of conservation agriculture is Limited adoption, limited knowledge and skills, dependence on herbicide and initial investment costs and so on.

Keywords: Conservation agriculture; climate change; conservation agriculture machinery; happy seeder; zero tillage.

1. INTRODUCTION

There is a growing consensus that achieving sustainable agriculture requires the adoption of Sustainable Intensification practices [1-3]. Conventional agricultural practices encourage soil tillage, crop residue burning, and external inputs, causing soil degradation by reducing organic matter, increasing erosion and compaction [4]. Stubble burning or crop residue burning is a common agricultural practice where straw or stubble left in the field after grain harvest is intentionally burned. This burning of agricultural residue is typically carried out as a means of land preparation for the next crop, to remove excess plant matter from the field or to control pests and diseases. Residue burning has been identified as a significant source of short-lived climate pollutants, including methane and black carbon. Methane is a potent greenhouse gas that contributes to global warming, while black carbon can have a range of negative impacts on air quality, including respiratory illnesses and reduced visibility [5]. Conservation agriculture, as defined by the United Nations' Food and Agriculture organisation (FAO), is "a farming system that promotes maintenance of a permanent soil cover, minimum soil disturbance, and diversification of plant species. It enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production".CA mainly has three principles: 1. Minimum soil disturbance (not more than 30% of soil disturbance) 2. Soil coverage with organic biomass (to mulch soil with the residue of harvest). 3. Crop diversification (to sow different crops using different methods at different times on a rotation in a one-year crop cycle on same piece of land which is also called a crop cycle) [6].In comparison to conventional tillage, the adoption of minimum tillage practices has been found to result in significant fuel and labor savings. Specifically, studies have shown that minimum tillage practices can save between 60-66% of the fuel required for land preparation and 70-74% of the labor required [7]. Conservation agriculture is important to key players in sustainable agriculture, including farmers, policymakers, and consumers. For farmers, conservation agriculture can lead to increased productivity and profitability by reducing the need for costly inputs like fertilizer and herbicides. It also helps to mitigate the effects of climate change by sequestering carbon in the soil and reducing greenhouse gas emissions. For policymakers, conservation agriculture can help to achieve sustainable development goals related to food security, environmental protection, and poverty reduction. It can also contribute to rural development by promoting more sustainable farming practices. For consumers, conservation agriculture can ensure the availability of nutritious and safe food by protecting soil health and reducing the use of harmful pesticides and fertilizers. In summary, conservation agriculture is an important farming practice that can benefit farmers, policymakers, and consumers by promoting sustainable agriculture, protecting the environment, and ensuring food security. In this research, the essential agricultural machinery and technology required for adopting conservation agriculture has been highlighted. Conservation agriculture is the ultimate need of today, so now there is a need to adopt conservation agriculture to bring sustainability in farming. Agricultural machinery

used in conservation agriculture, their benefits and the problems faced in their adoption. Conservation Agriculture (CA), are considered an essential pathway towards Sustainable Intensification of agriculture [8,9].

1.1 Difference between Conservation and Conventional Agriculture

The decomposition rate of soil organic matter is higher in tropical regions than subtropical and moderate climates due to higher temperatures [10]. Conservation agriculture involves minimal soil disturbance, use of zero tillage or NT, soil cover with green manure or crop residue (mulching), and crop rotation to improve soil structure, porosity, and organic matter accumulation while saving fuel, time, and labor. Conservation tillage improves soil fertility, water, and crop productivity, while no-tillage provides better soil protection than conventional tillage, which leaves only 1-5% of the soil surface covered with crop residues [11].

Conventional agriculture relies heavily on tillage operations like plowing, harrowing, and drilling to prepare the land for planting and weed control. Unfortunately, repeated tillage can harm soil structure, increase erosion and result in costly fuel and labor expenses. Furthermore, conventional tillage practices can expose soil to air and sunlight, leading to the oxidation of organic matter and the release of CO2 into the environment, contributing to climate change [12].

2. MACHINERY USE IN CONSERVATION AGRICULTURE

2.1 Zero Tillage Technology

Zero tillage, also known as no-till farming, is a type of minimum tillage where primary tillage is entirely avoided, and secondary tillage is restricted to seedbed preparation in the row zone only. This method involves planting seeds directly into untilled soil, leaving the previous year's crop residue undisturbed. One approach to practicing zero tillage is through till planting, where machinery performs four tasks in one operation: clearing a narrow strip over the crop row, opening the soil for seed insertion, placing the seed, and properly covering it. This is accomplished through the use of a wide sweep and trash bars to clear a strip over the previous crop row, while a planter-shoe opens a narrow strip into which seeds are planted and covered. In zero tillage, herbicide use is extended as vegetation present on the field must be destroyed before sowing. To accomplish this, broad-spectrum non-selective herbicides with relatively short residual effects, such as Paraquat and Glyphosate, are typically employed [13].

Zero tillage (ZT) has been shown to allow for timely planting of wheat, providing several benefits over conventional tillage (CT) methods. One such advantage is that ZT enables earlier sowing, which has been found to reduce competition from Phalaris minor, a herbicide-resistant weed that can negatively impact wheat growth and yields when wheat is sown late under CT [14,15].This process saves at least 15-20 days of land preparation and thus, shortens the duration which also increases 15- 20% wheat yield. So, this is the main reason behind the initiation of zero-tillage technology.

Fig. 1. Zero tillage

Benefits of zero-tillage technology: Zero tillage (ZT) is known to have a positive impact on soil quality across several dimensions, including improvements in soil structure, soil fertility, and soil biological properties. In rice-wheat systems, soil organic carbon levels are generally low [16]. However, research has shown that ZT soils tend to have higher organic carbon content compared to conventional tillage (CT) soils. It should be noted, however, that ZT soils also have a lower pH, which can be attributed to nitrification [17]. Zero tillage (ZT) technology can result in significant cost savings related to field preparation, with potential reductions of up to Rs. 3200 per hectare [18]. This method also saves time and labor, with potential reductions of 10-20%. Additionally, adopting ZT technology can lead to a significant decrease in fuel consumption, with potential savings ranging from 26.5-43.7 liters per hectare [13]. This not only results in reduced fuel costs but also in lower carbon emissions released into the atmosphere.

As a result, the use of ZT technology can promote more sustainable and cost-effective agricultural practices. Research has shown that adopting zero tillage (ZT) can result in significant water savings during the cultivation of wheat. Reported reductions in irrigation water use range from 20-35%. This is due to various factors, such as the increased water-holding capacity of untilled soil, improved infiltration rates, and reduced evaporation losses compared to conventional tillage methods [19]. Also, the weed problem which was a huge issue in wheat was significantly reduced due to zero-tillage technology.

2.2 Multi-Crop Zero Tillage Planter

The most distinctive feature of a Zero tillage machine are its tines which are also known as furrow openers. These are special types and call them T - inverted type of tines. The furrow opener has a high carbon bit (heated bit) for penetration and it is wider from here as it has to place seed and fertilizer in the proper place. In this, the fertilizer goes first and then the seed so there is some variation as the seed and fertilizer should not get in contact. A multi-crop planter is an agricultural tool designed to efficiently plant multiple crops in a single pass. This machine consists of three boxes - the first box is used for storing fertilizers, the second box for seeds, and the third box is used for planting special crops such as maize that require precise planting. These planters can handle variable seed sizes, rates, depths, and spacing for different crops with adjustments for row spacing, depth, and power transmission. They also have a precise seed metering system using inclined rotary plates with variable grove number and size for different seed size and spacing, providing flexibility for direct drilling of different crops with precise rate and spacing using the same planter, which is not possible with fluted roller metering drills [20].

2.3 Mechanical Transplanter

Current labor shortage in farm operations, the government is encouraging the use of mechanization in order to increase the profitability of farming. Mechanical rice transplanter plants the seedling on ridges. This is a floating type mechanical rice planter. This floats and presses it down and it goes up where our seedling gets planted as it moves forward. The component is called a rotating flat board and its job is to facilitate mat nursery. Its distance is 22 cm. This is a finger controller and it has fingers which we rotate. Besides this, we have a floating platform and it floats over puddled soil. There is the engine and its components. When we release it, the fingers get activated and it acts as a control to turn it on and off. This is the adjustment where we can adjust the distance between seed and seedling from 12 cm to 14 cm to control the seedling depth. Farmers are not following the mat type nursery production technique correctly, which is having a negative impact on the performance of the machine. Preparation of mat nursery requires about 40% of the total energy requirement for mechanical transplanting, whereas the energy share for traditional nursery under manual transplanting is only 11%, the cost of machine transplanting was found to be significantly lower at Rs. 1310/ha compared to manual transplanting, which cost Rs. 2463/ha. Furthermore, the cost of producing mat type nursery for mechanical transplanting was approximately 40% of the total cost, while the cost for traditional nursery was only 25% of the transplanting cost [21].

2.4 Happy Seeder

It can sow seeds and fertilizer in a single operation without tilling or disturbing the soil and can work with any type of crop residue, with a load of 10 to 12 tonnes. However, it requires a double clutch tractor with a uniform force of 400 to 500 rpm to run effectively. The machine has nine tines, a weight of around 740 kg, and can be used for different crops by attaching a multi-crop planter box. The depth controllers are important to ensure that seeds and fertilizer drop at the correct depth in all nine rows. The SMS (straw manager system) was also developed to equally distribute residue on the field in a uniform manner. The Happy Seeder is an effective solution to the problem of crop residue and can help in sustainable agriculture practices. According to a recent study, farmers who use the Happy Seeder technique can generate up to 20% more profits on average, compared to those who burn their crop residues [22,23] Discovered that in farmers' fields, sowing with the Happy Seeder resulted in an average yield increase of approximately 10% compared to traditional farmer practices. The use of Happy Seeder for direct drilling wheat can lead to a reduction of 7.5 hours per hectare in tractor time as compared to conventional tillage and sowing. However, the direct drilling method using the Happy Seeder may take slightly longer than using the zero till drill. Based on an estimated fuel consumption rate of 6 liters per hour for a typical 35 HP

tractor, the use of the Happy Seeder can save up to 45 liters of fuel per hectare [24]. According to [25], the use of a 9-row happy seeder increased wheat grain yield by 3.9%. However, [26] highlighted constraints to its adoption, including a low window of operation (only 25 days per year), lower machine capacity compared to conventional seed drills, inability to operate in wet straw, and a lack of straw spreaders on combine harvesters.

Fig. 2. Happy seeder (Photo: BISA/Love Kumar Singh)

2.5 Laser Land Leveler

The laser land leveler, also known as "Computer Manjha" locally, is a sophisticated computer-based technology that has revolutionized the way farmers level their fields in India. Traditional land leveling methods were unable to minimize elevation differences below 10 cm, leading to variations in crop production and water logging in low-lying areas. With the laser land leveler, the field is automatically leveled; reducing variability to a maximum of 2 cm. [27] research, laser leveling can lead to a 10-15% reduction in the operating time of agricultural machinery when compared to traditional leveling methods. This is due to the fact that laser leveling creates a more even surface, reducing the need for adjustments and repairs to machinery caused by uneven terrain. [28] conducted a study to examine the impact of laser land leveling on nutrient-use efficiency in Rice-wheat fields. The results of the study showed that there was a significant enhancement in fertilizer use efficiency in fields that were laser-leveled compared to those that were conventionally leveled. Additionally, agronomic efficiency was significantly improved in laser-leveled fields in a rice-wheat cropping system. These findings are significant for farmers, as they suggest that laser leveling can help maximize the use of fertilizers and other nutrients, leading to increased crop yields and profitability. By creating a more level surface for planting, laser leveling can ensure that nutrients are distributed more evenly throughout the field, reducing the risk of nutrient deficiencies or excesses in certain areas.

Fig. 3. Laser land leveler

3. ALLIED CONSERVATION AGRICULTURE FOR SUSTAINABLE INTENSIFICATION MACHINERIES

Conservation Agriculture for Sustainable Intensification is an approach to farming that aims to improve sustainability and productivity while reducing environmental impacts. Various machines are used in CASI to achieve these goals. The Combine Harvester is a machine that can harvest, thresh and winnow crops like rice, with a capacity of 21 to 22 acres per hour. The Super Straw Management System evenly distributes straw residue, allowing for the use of other supporting machines. The Straw Reaper cuts and chops stalks into small pieces for storage and use as fodder, while also producing an extra 50 to 100 kg of grain per hectare. The Reaper Combiner cuts and binds crops, saving time and labor. The Paddy Straw Chopper converts field residue into small pieces that can be buried in the soil, helping with soil sustainability. The rotary mulcher is a field equipment that is operated through a tractor's Power Take Off (PTO) shaft and has a 3-point linkage. It chops leftover paddy stubbles and straw in the field into small pieces that can be used as surface mulch, improving soil fertility and reducing the need for fertilizers. [29]. The Weeder is used for mechanical weeding, while the Sprayer evenly distributes liquid droplets for applying herbicides, pesticides, fungicides, weedicide, and micronutrients. The Raised Bed Planter creates a permanent bed for direct seeding or precision planting, saving water by only using it in the furrow.

4. PRACTICES IN CONSERVATION AGRICULTURE

4.1 Crop Diversification and Intensification

Crop diversification is to alternatively sow different crops in a sequence in the same piece of land in the same year to next year. And crop intensification is that instead of doing one crop, grow two crops and instead of two crops grow three crops in a sequence in same year.

4.1.1 Principles

Less profitable to high profitable with more sustainability

If our cropping system is very water loving i.e. requires a lot of water, then we can replace it with a less water loving crop within the same system i.e. one that requires less water and optimizes it.

If we repeating the same type of crop then it increases the biotic stresses like diseases, insects and also nutrient uptake. So, to break this, we move towards a less biotic stresses with changing cropping system.

If we diversify the cropping system, then the cropping system becomes more resilient to climatic shocks. Like if one crop gets damaged, then we can profit from the next crop. We also have a mixed crop where if one crop fails, the other is saved. If we add a third crop then farmers can benefit from at least two crops in case, if one gets damaged [30].

4.2 Herbicides Application

Zero tillage is a popular agricultural practice, but it can lead to an increase in weed growth, making the use of herbicides crucial. Conservation agriculture requires minimum tillage and herbicide use to manage weeds efficiently, reducing production costs. Crop sown with zero till technology after a paraquat application recorded significantly less dry matter of P. minor compared to zero till sown wheat without paraquat application as well as conventional tillage crop. This may be because all the emerged seedlings of weeds were killed by paraquat in the former treatment. The use of zero till technology, combined with paraquat application, can be an effective way to control weed growth and promote healthy crop growth. By reducing the need for manual weeding and other labor-intensive practices, farmers can save time and money while improving the overall efficiency and profitability of their operations [31]. These have particular date of application like 2 4-D is used within 30 to 40 days in wheat crop. In maize, laudis is used within 15 to 25 days. Using flat fan nozzles for pre and post-emergent herbicides is recommended, and it is best to avoid using nails for nozzle maintenance. Proper calibration of sprayers is crucial to ensure the right amount of herbicide is used. Calibration takes into account the speed of the person spraying, the capacity of the nozzle, and the pressure within the sprayer. The spraying person's speed affects the output, and increasing the flow rate of the nozzle or pressure of the spraying machine will increase output per hectare. Herbicides are a vital component of conservation agriculture as they help achieve the objective of sustainable income generation and increase productivity while maintaining a benefit cost ratio.

4.3 Nutrient Management

4.3.1 Leaf color chart

To manage the nutrient levels in plants, farmers can use tools such as the leaf color chart. The first is the leaf color chart which is a scale that has 5 or 6 green color strips. These strips go from yellowish green to deep green. Compare the color of the leaves with this chart. If out of 10 leaves, 6 leaves appear slightly yellow and the greenness of these leaves are less than number 4 on the color chart then we provide per acre 25 kg nitrogen to the farm. Normally, to identify the nitrogen status in the plants, we repeatedly use the leaf color chart at specific intervals be it a period of 7 to 14 days. Usually do this till 14 days after sowing but stop using the leaf color chart after flowering. This helps us to avoid excess use of nitrogen and increases the usage efficiency of nitrogen and crop productivity.

4.3.2 Green seeker

Green Seeker is sensor-based equipment that measures the NDVI value of plants, there is a sensor fitted at the bottom with a trigger. When we pull the trigger and go to the row of the plant, it keeps giving us a reading for as long as we have pulled the trigger. The reading is measured in terms of NDVI and ranges from 0.00 to 0.99 with a higher NDVI value signifying better health of the plant. The Green seeker helps us to prevent excess use of nitrogen. Provide the right amount of nitrogen which is required by the plant which indicates the health of the plant.

Table 1. Crop diversification in agriculture

Crop diversification applied	Crop diversification not applied
❖ Natural resource conservation and enhancement	❖ Soil degradation
❖ Increasing the profitability of small farm holding	❖ Nutrient imbalance
❖ Risk reduction Pest and disease control	❖ Threats of biotic stress
❖ Improvement of soil fertility	❖ Declining farm profit
❖ Pest and disease control	❖ Resurgence of disease and pest
❖ Minimizing the risk coverage and reducing the magnitude of risk due to mono cropping	
❖ Soil restoration	
❖ Enhance opportunity of cropping in aberrant weather situation	

4.4 Crop Residue Management

Indian agriculture annually produces 501.73 million tons of crop residues, of which 92.81 million tons are burnt. The northwestern states, such as Uttar Pradesh, Punjab, Maharashtra, Madhya Pradesh, and Rajasthan, have a 52.68 million ton residue surplus, and most studies only focus on these regions [32]. Farmers burn around 100 million tons of crop residues, causing environmental problems such as greenhouse gas emissions, loss of soil nutrients, and air pollution. To manage crop residue, farmers can use machines such as straw management systems, happy seeders, zero tillage machines, paddy choppers, reaper combiners, and mulcher. Crop residue can also be used for producing fodder, mushrooms, bio fertilizers, mulching, vermin-composting, energy source and ethanol [33]. However, paddy straw has issues with digestibility and low crude protein, which can be improved by treating it with urea.

Table 2. Benefits of conservation agriculture (CA)

Benefits	Description	Source
Environmental	• Reduction in soil erosion, and thus of road, dam and hydroelectric power plant maintenance costs • Improvement of water quality • Improvement of air quality • Biodiversity increase • Carbon sequestration potential could offset 40% of annual CO_2 emissions and slow climate change	[34-36]
Economic	• Time saving and thus reduction in labour requirement • Reduction of costs, e.g. fuel, machinery operating costs and maintenance, as well as a reduced labour cost • Higher efficiency in the sense of more output for a lower input	[36]
Agronomic	• The adoption of conservation agriculture can offer several agronomic benefits that enhance soil productivity • One of the significant advantages is the increase in organic matter, which helps in improving soil structure, water conservation, nutrient retention, and fertilizer use efficiency • By incorporating crop residues into the soil, conservation agriculture enhances the organic matter content of the soil, which initially impacts the top layer but eventually extends to deeper soil layers. The presence of organic matter in soil is crucial in maintaining an ideal environment for plant growth by enhancing water-holding capacity, soil aggregation, rooting environment, and nutrient retention. Thus, conservation agriculture can be an effective strategy for improving soil productivity	[36]

Table 3. Conservation Agriculture has Several Strengths, Weaknesses and Opportunities

Strengths:	Weaknesses:	Opportunities:
• Improved soil health: Conservation agriculture helps to improve soil health by reducing soil erosion, improving soil structure, and increasing soil organic matter. • Increased crop yields: Studies have shown that conservation agriculture can increase crop yields, especially in areas with degraded soils. • Reduced labor and fuel costs: By reducing the need for tillage, conservation agriculture can reduce labor and fuel costs. • Improved water management: Conservation agriculture can improve water management by reducing water runoff and improving water infiltration into the soil.	• Limited adoption: Despite its benefits, conservation agriculture has not been widely adopted, especially in developing countries. • Limited knowledge and skills: Farmers may lack the knowledge and skills needed to adopt conservation agriculture practices. • Dependence on herbicides: Conservation agriculture often relies on herbicides to control weeds, which can have negative impacts on human health and the environment. • Initial investment costs: Adopting conservation agriculture practices may require initial investment costs, such as purchasing equipment for planting cover crops.	• Government support: Governments can support conservation agriculture by providing incentives and subsidies for farmers who adopt the practices. • Increased awareness: Education and outreach efforts can increase awareness of the benefits of conservation agriculture and help to overcome knowledge and skills gaps. • Market demand: Consumers are increasingly demanding sustainably produced food, which could create market opportunities for farmers who adopt conservation agriculture practices. • Integration with conventional approaches: Conservation agriculture practices can be integrated with conventional farming practices where necessary to achieve the desired outcomes.

6. RESULT AND DISCUSSION

6.1 Conservation Agriculture for Sustainable Intensification Scaling: A System Approach

The main reason for a technology not being adopted is the lack of a system approach. The adoption process is affected by various factors such as socio-economic conditions of the farmer, access to resources, gender, and entitlement to land. The decision-making process of a farmer is complex and not just based on economic perspectives. The technology needs to offer a better value proposition than the current technology in use, increasing yield or lowering the cost of cultivation. The scalability and infrastructure required for successful diffusion are also important factors. Different stakeholders have a role to play in the diffusion of technology, including research and development institutes, government, donors, and private institutions. The process can be made effective with least resources by strengthening the convergence process and identifying the right role for each stakeholder.

6.2 Social-behavioral challenge

The adoption of conservation agriculture is complex and influenced by various factors such as the decision-making process, behavior, age, education, and communication channels [37] identified five characteristics of a successful technology, including relative advantage, complexity, compatibility, trial ability, and observability. Continuous reminders and peer pressure can influence farmers to adopt the technology. Risk-averse small cultivators in Eastern Gangetic Plains may be hesitant to invest in new technology due to fear of crop failure. Farmers may prioritize yield over cost savings, so designing messages to emphasize cost savings can increase adoption rates. The dual system theory suggests that decisions made after deliberation are more beneficial, and highlighting the environmental benefits of conservation agriculture can appeal to the altruistic side of people. Ultimately, increasing adoption rates of conservation agriculture requires a comprehensive approach that takes into account the various factors that influence farmer behavior and decision-making.

6.3 Access to Conservation Agriculture Machineries

Manufacturers face low demand for machines used in conservation agriculture, with seasonal business and difficulty in procuring quality parts. Local maintenance workshops are lacking, and trained technicians are needed. Spare parts are often ordered from Punjab, causing delays. To address these issues, increasing machine availability and opening community-based custom hiring centers for small farmers could help. Startups providing machines through custom hiring or service providers could also be a viable solution. This would increase the adoption of conservation agriculture, creating a larger market for these machines.

Socio-economic research can shift the focus from assessing farmers' readiness for technology adoption to assessing the readiness of the innovation system to support the farmers. To achieve this, a revised adoption framework guided by a Theory of Change based on regional level enabling and constraining factors, is needed to generate data that can facilitate the widespread dissemination of new technologies [38-40].

7. CONCLUSION

India produces 500 Mt. of crop residue annually on average. There is a massive surplus of 140 Mt., out of which 92 Mt. is burned annually, primarily in the northern states such as Punjab, Haryana, and Uttar Pradesh, even though the majority of it is used as fodder, a raw material for energy production and so on. Conservation agriculture is a sustainable alternative to conventional tillage that improves soil health and productivity while reducing labor, fuel, and environmental costs. Zero tillage technology is a promising approach for sustainable agriculture, allowing for timely planting and improved crop yields while minimizing environmental impact and reducing labor and fuel costs. The multi-crop zero tillage planter is a versatile agricultural tool that allows for efficient planting of multiple crops with precise spacing and rate, while minimizing soil disturbance and promoting sustainable agriculture practices. Mechanical rice transplanter can alleviate labor shortage and increase farming profitability. Mat nursery preparation is crucial for machine transplanting. The Happy Seeder is a sustainable solution for crop residue, increasing profits up to 20% and yield by 10%. Constraints include low window of operation and machine capacity. The laser land leveler is a sophisticated technology that minimizes elevation differences to a maximum of 2 cm, reducing variability and enhancing nutrient-use efficiency. It can also reduce operating time by 10-15% and increase crop yields and profitability. Crop diversification and intensification increase productivity and sustainability by alternating crops and growing multiple crops in the same land. Conservation agriculture is an important farming practice that can benefit farmers, policymakers, and consumers by promoting sustainable agriculture, protecting the environment, and ensuring food security.

Crop residue decomposition can immobilize nitrogen, reducing nutrient availability for plant uptake. Minimum tillage without fertilizers can lead to nutrient immobility, resulting in lower yields. Tilling accelerates residue decomposition, but nutrients are only available for the short term. Weed control is a key reason for tillage, but reduced tillage increases weed pressure, requiring more labor for control. Herbicides can overcome this constraint in conservation agriculture. However, minimum tillage without herbicides faces challenges in controlling perennial weeds. A balanced approach to conservation agriculture is necessary for sustainable and productive agriculture. Now there is a need for research with more discoveries, like; limited adoption, limited knowledge and skills, dependence on herbicide initial investment and so on, so that these shortcoming into advantage.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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