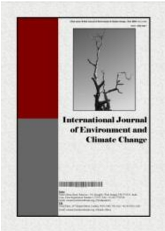

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Impact of Rice Residue Management Practices on Environment, Productivity and Economics of Wheat: A Review

Preetam Kumar [a], Sandeep Rawal [a], Raj Kumar [a*] and Kavita [a]

[a] *Department of Agronomy, CCS Haryana Agricultural University, Hisar – 125004, Haryana, India.*

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

Rice-Wheat (RW) is a major cropping system followed in Indo-Gangetic Plains of India. This cropping system popularised with mechanisation of both mentioned crops. Increase in mechanisation, particularly use of combined harvesting enables harvesting of rice in a very short span of time but it leaves behind a large amount of crop residue. Ex-situ residue management of this voluminous residue is not feasible and economical to the farmer. Burning of rice residue is a common practise in India to manage the rice residue because of its low economic use, which causes serious air pollution and nutrient losses. Sustainability of RW system is at risk due to soil degradation and poor residue management practices. Proper in-situ residue management is of utmost importance as crop residue contains significant amount of nutrients and it can improve soil physical, chemical and biological health because of huge amount of organic carbon added to the soil. Various soil properties, wheat productivity, economics and the environment are highly influenced by the rice residue management practices adopted. In this review, the authors have discussed impact of different rice residue management practices and wheat sowing methods on wheat productivity, economics, soil properties and the environment.

Keywords: Conservation; Indo-Gangetic plains; mulch; maturity; sustainability.

**Corresponding author: E-mail: aasiwalraj@hau.ac.in;*

1. INTRODUCTION

Rice (*Oryza sativa* L.) – wheat (*Triticum aestivum* L.) is a major cropping system of India. Out of 620 MT crop residues produced annually in the country, 234 MT is surplus and 30 per cent of it is contributed by rice wheat. About 16 per cent of total crop residue being burnt, 62 per cent is contributed by rice and wheat [1]. Combine harvesting of crop in rice-wheat cropping system leaves behind substantial quantity of crop residues. Crop residues are the plant parts left on cultivated land after the crop has been harvested. Factors like shortage of labour, high wages during harvesting season and; timely and cheap harvesting with harvester compared to manual labour led to an increase in number of harvesters [2]. Uncertain and aberrant weather was also identified as a factor influencing rise of combine harvesters [3]. Combine harvesting allows farmers to harvest the rice crop more quickly and efficiently, and leaves loose straw on the ground which creates difficulties in sowing of wheat crop in loose paddy residue loaded fields. The farmers depending on the situation and available resources; adopt several residue management options like burning, incorporation and mulching. Crop residue burning started with the mechanized harvesting of wheat and rice crop. This mechanization increased the residue burning incidences, [4] as burning permits the preparation of field for sowing of next crop rapidly and economically [5] and farmers obtains the benefit of cost and time saving [6]. According to a study published in *Science* Magazine in August 2019, farmer in north India burn an amount of rice straw, which if packed into 20 kg, 38 cm high bales and piled on top of each other, would reach a height of over 4,30,000 km or about 1.1 times the distance of moon [7]. As per Department of Soils, PAU Ludhiana, due to one tonne stubble burning, the soil loses about 6-7 kg N, 1-1.17 kg P, 14-25 kg K and 1.2-1.5 kg S. About 95 lakh tonnes of organic carbon is lost every year due to burning. Stubble burning every year causes loss of about 80 kg of urea, 13.75 kg DAP and 128 kg Potash. The loss of fertility leads to loss of one quintal extra yield of wheat crop [8].

Before mechanization, farmers used to harvest the crop manually near the soil surface and there was no heavy load of loose rice residue, as residue generated was also used for animal bedding, feeding, roof thatch and other domestic purposes. But, mechanical harvesting of rice leaves huge quantity of crop residue with uneven distribution in the field and; collection and disposal of this voluminous amount of residue is very cumbersome and uneconomical. Also, rice straw is considered a poor feed for cattle due to its high silica content. So, burning of crop residues is the only easiest, time saving and economical option left to farmers. Generally, farmers account for private cost and benefits of residue burning but ignores its external social and environmental cost. Intensive cropping systems are often the most challenging for sustainable management of crop residues because of the short time interval between the crops. Delay in sowing of wheat after optimum period can result in adverse conditions such as low temperature during the seed germination, low tillering capacity and low plant population [9]. It can also lead to late blooming, exposing the crop to high temperature during the grain filling period and; higher temperature boosts the reproductive development and reduce the grain filling period [10,11] adversely affecting the grain yield. Delayed sowing also results in yield loss of 1 per cent per day mainly due to suppression of crop growth, leaf area index and biomass production [12].

Crop residues are not only a source of significant quantity of nutrients for crop but also improves the soil physical [13], chemical [14] and biological [87] functions and properties. Proper management of crop residues affect the soil quality either directly or indirectly. Instead of burning, alternate residue management practices can contribute to improved soil health, long-term sustainability and mitigation of climate change related greenhouse gases concentration in the atmosphere by reducing carbon dioxide emissions [15]. Conservation agricultural practices with reduced tillage, residue as mulch, improved crop establishment etc. are need of the hour to manage degrading soil health and to overcome yield stagnation. Several mechanization options in the form of combine fitted with SMS (super straw management), happy seeder, zero seed cum fertilizer drill machine, mulcher, paddy straw chopper, shrub master, reversible MB plough, baler etc. has been proposed to solve this problem of stubble burning [16]. Conservation agriculture practices like zero tillage sowing of wheat using zero till drill or happy seeder directly into the combine harvested paddy field enables the farmer to reduce input cost, increase profitability, conserve water, labour, energy, soil nutrients and farm chemicals along with enhanced crop growth and yield. Retention of crop residue returns organic matter to the soil and also affect the soil nutrient recycling [17]. Crop residue left on soil might reduce available form of nutrients such as N by the process of immobilisation.

The loss of soil organic matter is also posing one of the major threats to rice-wheat sustainability. Handling of the rice residue with suitable machinery provide sustainable management option of rice-wheat cropping system. In-field retention of crop residue can play a significant role in replenishing soil organic carbon and nutrient pool. In this review an attempt is made to study the impact of different rice residue management practices and wheat sowing methods on wheat productivity, economics, soil properties and the environment.

2. IMPACT OF RESIDUE MANAGEMENT PRACTICES

2.1 Adopting Residue Burning

Characterisation analysis revealed that 84% of crop residue burning is from rice-wheat cropping system alone while, remaining 16% is from other types of crop rotations [18]. Burning reduces the soil nutrient availability and leads to loss of soil organic matter. Complete burning of rice residue results in loss of 100% nitrogen, 20.1% phosphorus, 19.2% potassium and 80.2% sulphur [19]. Study by GoI [20] reported that burning of one tonne of rice straw accounts for loss of 5.5 kg of nitrogen, 2.3 kg phosphorus, 25 kg potassium and 1.2 kg of sulphur.

Degradation of air quality due to straw burning is also a major concern and several studies have suggested significant impact of biomass burning on air quality including burning of rice-wheat residue in Punjab [21,22,23]. Kumar et al. [24] concluded that burning of one metric tonne of straw releases 3 kilograms of particulate matter, 60 kg of CO, 1460 kg of CO_2, 199 kg of ash and 2 kg of SO_2. Yin et al. [25] reported that the largest contribution (48 per cent) to annual average concentration of $PM_{2.5}$ was from biomass burning, followed by anthropogenic emission (27 per cent) and long-range transport/local natural source (25 per cent). Gupta et al. [26] also reported that rice residue burning increases global warming due to emission of various greenhouse gases, which includes 70% carbon dioxide, 7% carbon monoxide, 0.66% methane and 2.09% nitrous oxide and gases such as CO and nitrogen oxides (NO_x) acts as precursor of tropospheric ozone (O_3). Also, some amount of non-methyl hydrocarbons, volatile organic compounds, particulate matter $PM_{2.5}$ (with an aerodynamic diameter of less than 2.5 μm) and PM_{10} (with an aerodynamic diameter of less than 10 μm) are released with residue burning, which contribute enormously to global warming [27,28]. During the rice harvesting period, particulate matter level in the ambient air increases much beyond the permissible limit of $PM_{2.5}$ and PM_{10}, which affects the respiratory health [29]. The monthly average values of $PM_{2.5}$ and PM_{10} in the Malwa region of Punjab during the crop residue burning period were reported about 3-4 times higher than the National Ambient Air Quality Standards (NAAQS) given by central pollution control board [30].

Crop residue burning during winter season produces a thick cloud of smoke and poses threat to human health by deteriorating the air quality [31]. Exposure to smoke of residue burning affect the human pulmonary function, causes eye irritation, asthma, corneal opacity and skin diseases. Agriculture crop residue burning has become a serious environmental hazard and poses unrecoverable influence on the pulmonary health in humans [32] affecting more which are having the lower body mass index [33]. Fine aerosol particles released during burning leads to turbid atmospheric conditions [34], which increases the incidence of road accidents and; discomfort due to delay or cancellation of trains and flights due to poor visibility. As a protection measure, National green tribunal has banned burning of straw in Delhi and four northern states- Punjab, Haryana, Rajasthan and Uttar Pradesh.

Residue burning affects the nutrient pool and harm soil properties, thus indicating the need for improvement in harvesting technologies and sustainable management of rice-wheat cropping system. Gupta et al. [26] reported that residue burning elevates the soil temperature, which affects the soil ecology. The presence of crop residue promotes high microbial activity, moisture conservation, increase in carbon stock, lower soil temperature and lower CO_2 emission. The unburned system presents a higher potential for stabilising the soil organic carbon and sustainability of the system.

2.2 Avoiding Residue Burning

When crop residues are retained, they may either be left on the soil surface or incorporated into the soil. Complete or partial retention of residue either by incorporating or leaving them on the soil surface is more advantageous than its complete removal [17] and have a number of benefits on soil quality [35]. Soil quality was improved by incorporation of rice straw through enhanced nutrient cycling and soil organic carbon sequestration which provide the soil fertility benefits. Crop residues are an important source of nutrients and; surface retention of residue affects the physical, chemical and biological properties of soil contributing to increased yield [36,37]. Residue retention is considered as a nutrient conserving measure that effectively increases soil fertility and soil N availability. Zhang et al. [38] conducted a 6-year experiment of straw incorporation at Changshu Agro-Ecological Station in a field under rice-wheat cropping system and revealed that incorporating crop residue of either rice or wheat or both crops significantly reduced the soil nitrogen loss compared to non-addition of crop residue.

Rice based cropping system has depleted a significant amount of soil organic carbon and threatened the sustainability of agriculture. Incorporation of crop residue improved the soil organic matter, soil particles aggregation, cation exchange capacity, available nitrogen, phosphorus, potassium and saturated soil water content in the soil as reported by Zhao et al. [39]. Reduced and no tillage significantly improved the soil organic carbon compared to burning and conventional tillage as straw returned to the soil plays an important role in increasing the organic carbon [40,41]. Minimum and zero tillage technologies for wheat sowing are beneficial in terms of economics, saving of irrigation water and timely sowing of wheat in comparison with conventional tillage [42,43]. Zero-till sowing of wheat saves operational cost hectare^{-1} by reducing the number of tillage operation carried out and low expenses on human labour compared to the conventional tillage. However, lack of suitable machinery is a major constraint to direct drilling of wheat in combine harvested rice fields due to presence of heavy loose straw left by the harvester. Sowing of wheat into rice stubble using the zero till seed drill is however impaired due to lose straw in the furrow openers, traction problem with the drive wheel of seed and fertilizer metering system and non-uniform sowing depth due to frequent lifting of the drill to clear the blockage caused by the loose paddy straw. To overcome the problem faced during direct sowing into the rice residues, happy seeder was developed. Happy seeder enables direct sowing of wheat crop after combine harvesting of paddy.

3. IMPACT OF RESIDUE MANAGEMENT PRACTICES ON GROWTH, YIELD ATTRIBUTES AND YIELD OF WHEAT

The conventional tillage practices have adverse effect on the wheat productivity, use high energy and fuel and reduces the economic returns of wheat production system. Soil tillage system decides the fate of crop residue and influence the soil nutrient dynamics. Conservation agriculture-based retention of crop residue provides multiple benefits like soil moisture conservation, improvement in soil organic matter, soil structure, suppression of weeds and improving the farmer’s income [44]. Also, the resource conservation technology improves yield and reduce the negative impact on environmental quality in rice-wheat cropping system [45]. Ram et al. [46] also reported higher wheat yield under zero tillage with residue due to low soil and canopy temperature, higher soil moisture availability, more tillers and 1000-grain weight than zero tillage practice with no residue as well as conventional tillage practices. Bhatt et al. [47] also stated that adoption of resource conservation technologies, such as zero tilled wheat sowing is considered essential to maintain the productivity of the rice-wheat cropping system. Higher plant height, 1000-grain weight, grain yield, straw yield and harvest index in wheat were reported by Singh et al. [48] while comparing residue incorporation with residue removal and burning conditions.

Similarly, Kumar et al. [49] also reported higher ear length, test weight, grain yield and straw yield in zero till wheat under retention of crop residue compared to the treatment with removal of crop residue in rice-based cropping system.

Wheat sowing by turbo happy seeder produce higher grain yield over conventional method due to mulching effect and happy seeder sowing also curtails the overall cost of cultivation [50]. Sidhu et al. [51] demonstrated that the yield of wheat seeded into rice residues with the turbo happy seeder is comparable to or higher than the yield of wheat sown into rice residues with straw burning and conventional tillage prior to sowing, while also giving numerous benefits to the farmer. A two-year economic examination of data from a six-year on-farm demonstration revealed that the zero-tillage method of wheat growing is the most cost-effective and appealing alternative for the farmers of central Uttar Pradesh. In comparison to conventional wheat sowing, zero tilled wheat sowing produced higher grain yields, lower cultivation costs, lower weed density (particularly Phalaris minor), and saved more water. Similarly, Gill et al. [52] stated that zero tillage could save 20 percent irrigation water along with saving of 300 million litres of diesel per annum while Mirani and Dahri [53] also reported that direct drilling of wheat in rice stubbles resulted in saving of 15 percent irrigation water and 23.9 percent increase in water productivity as compared to conventional tillage. Khalid et al. [54] conducted a trial in Pakistan and found that tillage methods with straw retained/incorporated yielded greater grains spike-1, 1000 grain weight, and grain yield than tillage techniques with straw burned. Similarly, Yadvinder-Singh et al. [55] also reported 7 per cent increase in yield of wheat sown with straw mulch-zero till compared to wheat sown after residue burning.

Iqbal et al. [56] conducted an experiment to evaluate the happy seeder zero tillage (HSZT) technology of wheat sowing compared to conventional method during 2014-15 and 2015-16 at Gujranwala, Pakistan and concluded that HSZT produced higher germination count, higher number of fertile tillers and higher 1000-grain weight as compared to conventional method of wheat sowing. Higher grain yield (3030 and 3920 kg ha^{-1}) was recorded by HSZT as compared to conventional method (2836 and 3478 kg ha^{-1}) in first and second year, respectively. In a four-year study, Thind et al. [57] observed that zero till sowing of wheat with all the rice residue retained as a surface mulch resulted in higher wheat grain yield by 7.3 percent and 17.5 percent when compared to conventional till wheat with rice residue removed and zero till wheat with rice residue removed, respectively.

Kharia et al. [58] reported that sowing of wheat using happy seeder with retention of rice straw as surface mulch recorded higher grain yield than other treatments. In happy seeder sown wheat, yield parameters such as 1000-grain weight, spike length, grain weight per spike, and number of grains spike-1 were also greater. Conservation agricultural approaches, according to the study, provide a better soil environment for crop growth and development, which could lead to increased grain yield and nutrient uptake.

4. IMPACT OF RESIDUE MANAGEMENT PRACTICES ON SOIL PROPERTIES

The traditional practice of wet puddling in rice and conventional tillage in wheat is deteriorating soil health resulting in yield stagnation of the cropping system. Careful monitoring of tillage and residue management practices is necessary to avoid further deterioration in ecosystem services provided by the soil. Conservation agriculture practices involving minimum soil disturbance, retention of crop residues improves the soil health. Crop residue and tillage management practices affect the soil properties and ultimately affecting the crop yield and sustainability.

4.1 Soil Physical Properties

Soil physical properties are important indicators of soil quality and play a role function in crop production. Intensive agriculture cause soil deformation resulting the change in soil properties. Deterioration of soil physical properties have been credited to tillage for rice-wheat system. Conservation tillage has a positive influence on different soil properties such as penetration resistance, bulk density, and soil water content. Soil physical status change with tillage practices and affect the water, air and thermal regimes of the soil [59].

Bulk density is a dynamic property and reflects the soil aeration, water and soil movement and structural support. Bulk density affects the root penetration influencing the crop yield and soil erosion. Bulk density and organic matter exhibit a positive correlation between them [60]. Chalise et al. [61] reported that residue retention results in 7 per cent lower bulk density compared to no retention of crop residue. Showing the effect of tillage practices, Li et al. [13] reported that no-tillage, no-tillage with residue retention, and reduced tillage increased the bulk density by 1.4, 2.6, 2.1 per cent respectively, compared to conventional tillage. The bulk density was lower by 2.9 per cent in no-tillage with residue retention compared to no-tillage without residue and 3.9 per cent lower in reduced tillage with residue retention compared to reduced tillage without residue. Gozubuyuk et al. [62] also reported higher bulk density under no-tillage compared to reduced and conventional tillage. Aikins and Afuakwa [63] compared no-tillage with tillage operations carried out using disc plough with disc harrow and observed that no tillage plots produced highest bulk density and lowest total porosity.

Penetration resistance is common method to assess soil strength and it provides a good representative indicator of soil compaction under different tillage conditions [64]. Penetration resistance affect the root growth and root growth decreases with increasing penetration resistance. Gozubuyuk et al. [62] conducted an experiment to compare the penetration resistance of conventional tillage, reduced tillage and no-tillage and observed lowest penetration resistance in conventional tillage practice while higher penetration resistance was reported under no-tillage and reduced tillage. Gathala et al. [65] also reported that soil penetration resistance was significantly influenced by tillage, crop establishment methods and residue management up-to 25 cm soil depth. Penetration resistance was significantly higher in conservation agriculture treatments as compared to the conventional agriculture treatments.

Presence of crop residue on the soil surface decreases the loss of water by evaporation [66] and enhances the formation of a thin layer on the top of bare soil which hinders the turbulent vapour exchange between soil and the atmosphere [67] and help in reduction of number of irrigations applied. Retention of crop residue as mulch on soil surface was helpful in improving the moisture retention and water productivity [68]. Yadav et al. [69] studied the effect of tillage treatments including conventional tillage with 100 percent residue incorporated (CT-RI) and no-till with all the residue retained (NT-RR) and reported that NT-RR stored more soil moisture in comparison to CT-RI during crop growing season. Similarly, Page et al. [70] during a long-term study also reported higher soil moisture storage in no-tillage with residue retained than conventional tillage with stubble burning.

Besides conservation of soil moisture, tillage and surface residue also influence the soil microclimate. Crop residues left on the soil surface influence the reflection of solar radiations. The effect of reflection depends on amount and thickness of residue. Soil temperature fluctuations are reduced with crop residue as surface mulch [71].

4.2 Soil Chemical Properties

The chemical aspects of soil are of extreme importance for the correct balance of available nutrients in the soil. The chemical components of soil affect reactions and processes of soil environment. Important chemical properties of soil which are affected by different tillage and residue management practices are soil pH, EC, OC, cation exchange capacity and nutrient availability to the plant.

Soil pH is important factor determining soil fertility affecting the nutrient availability. Crop residue can affect soil pH which in turn may affect their decomposition. Clark et al. [72] observed an increase in soil EC in lucerne and wheat crop residue amended soil compared to the control plot. Limousine and Tessier [73] also reported that conservation agriculture management, especially no-till decreases soil pH relative to conventional practices in the upper 5 cm soil layer probably due to accumulation of organic acids released by residue decomposition. Butterfly et al. [74] reported increase in soil pH on addition of crop residues. Decarboxylation of organic anions and the interaction of H+ ions with organic anions and other negatively charged chemical functional groups were blamed for the increase. Virk et al. [75] during a two-year field experiment reported that soil pH, EC, OC were not significantly affected by sowing with happy seeder, straw chopper + zero till sowing and conventional sowing. However, a slight decrease in pH and increase in OC was observed with happy seeder sowing and straw chopper + zero-tillage sowing. Wang et al. [76] reported that soil pH was reduced in residue amended soil compared to non-residue amended treatment.

As a reservoir of soil nutrients, soil organic carbon is an important measure of soil quality and agricultural sustainability. Dolan et al. [77] observed that soils with no-tillage had more than 30 percent higher soil organic carbon and nitrogen than mouldboard plough and chisel plough tillage treatments. Alam et al. [78] conducted a study to investigate the effect of medium-term tillage practices on soil properties and crop yield in Grey Terrace soil of Bangladesh. The highest organic matter accumulation, the maximum root mass density and improved soil physical and chemical properties were observed under conservational tillage practices. Highest total N, P, K and S in their available form were observed in zero-tillage practices. Hati et al. [79] observed that soil organic carbon content was significantly higher in no-tillage, reduced tillage and mouldboard tillage with wheat residues retained than the conventional tillage system.

In addition, Naresh et al. [80] found that using rice straw mulches for a short period of time could boost wheat production and improve the quantitative and qualitative properties of soil aggregates and soil organic carbon (SOC) when compared to standard agricultural practises. Kharia et al. [58] reported significantly higher uptake of macronutrients and micronutrients under happy seeder sown wheat with retention of rice crop residue as surface mulch compared to conventional tillage without rice straw.

Mondal et al. [81] reported that adoption of reduced tillage and reduced tillage with 30 percent as residue increase the soil organic carbon compared to conventional tillage practices and also concluded that retention of crop residues and reduced tillage could significantly improve soil health and organic carbon content. Similarly, Zahid et al. [82] also reported significant impact of conservation tillage practice on soil organic matter, total nitrogen, available phosphate, available potassium compared to conventional tillage practice.

Saurabh et al. [83] conducted an experiment at Patna during 2015-2018 in a randomised block design with three replications reporting higher macro aggregate stability (47 per cent), soil organic matter (18 per cent) and microbial biomass counts (56 per cent) under zero-till direct seeded rice-zero till wheat than random puddled transplanted rice-conventional till broadcast wheat and concluded that crop residue retention on the surface with zero tillage is beneficial for the sustainable production of rice wheat cropping system.

5. IMPACT OF RESIDUE MANAGEMENT PRACTICES ON ECONOMICS OF WHEAT

Direct sowing of wheat using conservation tillage practices helps to curtail the cost of cultivation incurred in various tillage operation carried out before sowing of crop. Reduction in cost of cultivation help the farmers to fetch better economic returns. Gill and Singh [84] compared wheat production under different residue management methods and concluded that cost of cultivation in happy seeder sown wheat was 15.2 per cent less than sowing of wheat with normal drill after burning of paddy residue. Happy seeder sowing resulted in 2 per cent higher gross returns and 5.5 per cent higher net returns over normal sowing after residue burning. Similarly, Kumar et al. [49] reported higher net returns in wheat sown under residue retention than wheat sown with removal of crop residues.

Happy seeder allows the sowing of wheat crop without burning of crop residue and its retention enhances the soil productivity. Happy seeder combines residue mulching and seed drilling function in one machine. Omitting the conventional cultivation practices of land preparation on account of zero tillage reduces the cost of cultivation. Singh et al. [85] conducted an experiment on use of happy seeder and rotavator for sowing of wheat in combine harvested field for in-situ management of rice straw and concluded that happy seeder was an efficient method to reduce the cost of production and management of combine harvested fields. Saving of 5.38 hrs time, 16.03 litres diesel and ₹ 3250 per ha was observed with happy seeder compared to farmer’s practice. Also, the average gain yield of wheat sown with happy seeder was slightly higher by 1.03 q ha^{-1} than wheat sown with farmer’s practice. However, adoption of happy seeder is low due to low window of operation of the machine (25 days per year), inability to work under moist straw condition, low machine capacity compared with conventional seed drills and the lack of straw spreaders on combine harvesters [86]. Iqbal et al. [56] also reported that happy seeder zero tillage (HSZT) gave higher net economic returns (₹112938 ha^{-1}) with cost benefit ratio (CBR) of 1:1.51 as compared to conventional method with net returns of ₹102602 ha^{-1} and CBR 1:1.33.

6. CONCLUSION

Crop residue plays an important role in increasing crop yield, soil organic carbon sequestration and reducing the greenhouse gases. Residue retention increases the proportion of soil organic carbon and other nutrients. Conservation agriculture with reduced or zero tillage can decrease the energy input and cost of cultivation to farmer which ultimately increases the monetary returns. Even though the farmers are aware of adverse effects of paddy residue burning, they are constrained by the lack of timely availability of conservation agriculture machinery and their high prices.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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