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SMART RESIDUE MANAGEMENT: FROM WASTE TO WEALTH AS INNOVATIVE APPROACHES FOR RICE-WHEAT CROPPING SYSTEM IN WESTERN IGP

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ABSTRACT
Increasing scarcity of natural resources due to intensive tillage operation along with rising the cost of cultivation are major challenges for the sustainability of rice-wheat system in the western Indo-Gangetic Plains (IGP). The innovative approaches to manage crop residues is vital for the improvement in soil quality and factor productivity under RWCS of western IGP. Crop residues, usually considered as waste material, if managed appropriately with innovative technologies can improve soil organic carbon stock and nutrient cycling in long term.

Introduction

Rice and wheat are exhaustive feeders, heavily depleting the soil nutrient content. Many soils under rice-wheat system in the IGP are poor in organic matter and nutrient supplies. Singh *et al.* (2015) investigated that depletion of soil nutrients under rice-wheat cropping system (RWCS) are the key factor for reducing productivity in the IGP. Increases in the productivity of RWCS in future will greatly depend upon improvements in soil productivity through proper management and utilization of crop residues. In general, crop residues are parts of the plants which left in the field after crops have been harvested and threshed. These materials at times have been regarded as waste products that require removal or burning practice in recent past, but it has become increasingly realized that they are proved important source of various plant nutrient and not waste material. It also maintains the soil physical and chemical properties while, improves the overall ecological balance of the production system. A decline in land productivity, particularly of the RWCS, has been observed over the past few years in the western IGP despite the application of optimum levels of inputs under assured irrigation. Rice straw that remains unutilized and is generally burnt in the field as the loose straw interferes with tillage and seeding operations for the subsequent wheat crop. Burning of residues will leads to loss of soil organic matter and plant nutrients besides causing environmental pollution and emission of green house gases. Reduced or zero tillage for wheat has been increasingly adopted by farmers because it leads to decrease the cost of cultivation through reduced use of fuel and labor, and early sowing leading to potential yield benefits, especially after late harvested rice in the western IGP. While, the high rice residue load hinders the use of zero-till seed drills due to obstruction of the machinery with loose straw. Thus, zero-tillage sowing of wheat is possible only after complete or partial removal of residues in rice fields. Western IGP farmers typically lack suitable techniques to handle large amount of residues, particularly of rice straw in machine-harvested areas. Recent developments of machinery, happy seeder provide the better means for sowing under loose residue retention situation instead of incorporation or burning. However, management of the rice straw is a major challenge as it is considered to be a poor feed for the animals owing to high silica content. Several management options available to farmers for the management of rice residues. Farmers use different straw management practices as per the situation, availablity of machinery, technical knowledge and available time between rice harvesting and wheat sowing. Keeping these points in view there are several management practice that adapted by farmers of IGP are described as under.

Residue management options for IGP

1. Residue burning

Recently, with the advent of mechanised harvesting, farmers have been burning *in-situ* large amount of crop residues left in the field as crop residues obstruct with tillage and seeding operations for the subsequent crop. Many farmers chop-off the rice stubbles with a stubble shaver, dry them and burn completely to facilitate timely planting of wheat leading to higher environment footprints. Thus, burning is a option but it leads to large losses of plant nutrients. This practice also causes significant air pollution and killing of beneficial soil microorganisms. However, burning also kills soil borne lethal pests and pathogens. One of the hypothesis of burning is that it clears the land rapidly before succeeding crop and facilitate timely sowing of succeeding crop. When burnt, the residues instantly generate as much as 13 t of CO_2 ha^{-1}, contaminating the air, stingy soils of organic matter. This loss of SOM is one of the recognized threats to rice-wheat sustainability.

Fig. 1. Environmental pollution caused by burning of rice residue

Table 1. Nutrient content in rice straw and amount deducted with 1 tonne of straw residue removal

Treatments	**N**	**P_2O_5**	**K_2O**	**S**	**Si**
Content in straw, % dry matter	0.5-0.8	0.16-0.27	1.4-2.0	0.05-0.10	4-7
Removal with 1 tonne straw, kg/ha	5-8	1.6-2.7	14-20	0.5-1.0	40-70

Source 'Rice straw management'; (Dobermann and Fairhurst, 2002)

2. Surface retention and mulching

Direct sowing in surface mulched residues is a practice that leaves straw residues from a preceding crop on the soil surface without any tillage. No tillage technology for wheat after rice proved better in terms of saving of diesel, production cost and advancing sowing time compared to rotavator and conventional tillage. Surface retention of some or all residues may be the best suitable option in many situations where residues decompose slowly on the surface, increasing the organic carbon and total nitrogen in the soil, while protecting the surface soil from erosion. However, it provides habitat for useful organisms and also provides carbon substrate for heterotrophic nitrogen fixation, increase microbial activity, soil carbon and nitrogen and reduce fertilizer nitrogen requirements for succeeding crop. The faster decomposition and release of nitrogen to soil is possible if it is treated with urea and applied before sowing operations. CRs retained on the soil surface provide soil and water conservation benefits, and increase subsequent crop yield while increasing the sustainability of cropping system. The potential benefits of no-till can be fully realized only when it is practiced continuously and the soil surface should remain covered at least 30% by previous CR. The use of new-generation planters (Happy seeder) will lead to wider adoption of conservation agriculture in the region. The Happy seeder works well for direct drilling in standing as well as loose residues, provided the residues are spread uniformly.

Fig. 2. Residue management with happy seeder under rice residue retained situation

3. Straw incorporation

Ploughing is the most efficient residue incorporation method. Incorporation of the remaining stubble and straw into the soil returns most of the nutrients and helps to conserve soil nutrient reserves in the long term basis. Short-term effects on grain yield are often small (compared with straw removal or burning) but long-term benefits are significant. Where mineral fertilizers are used and straw is incorporated, reserves of soil N, P, K, and Si are maintained and may even be increased. However, the practice of *in situ* rice straw incorporation as an alternate to burning has been adopted by only a few farmers because of high incorporation costs and energy and time intensive.

Fig. 3. Residue incorporation under loose residue after harvesting of rice

4. Baling and removing the straw

Surplus straw from agriculture may be used for a number of valuable purposes such as livestock feed, fuel, construction materials, livestock bedding, bedding for vegetables such as cucumber, melons etc. and mulching for orchards and other crops. Straw removal can involve raking loose straw, baling it in small bales and stacking bales on roadside or custom hiring the entire operation. Straw cut low from the combine and left in a windrow may simply be baled and hauled. However, some growers may choose to swath the stubble, thus generating more tonnage of baled straw but at a higher total cost (for removal and storage). More complexity in removal methods will evolve as the bale format (round, square, large or small, etc.) is determined by end use. In the future, residue baling costs may be offset by revenues received from sale of the straw. Possible uses of rice straw range from bedding in horse stalls and chicken coops to serving as an ingredient in bricks, wallboard and other building materials.

Fig. 4. Baling techniques of residue manangement after harvesting of rice by combine machine

Residue management effects on soil properties

Soil physio-chemical properties, though interrelated are affected by the residue management practices.

1. Soil physical properties

Residue management practices affect soil physical properties such as soil moisture content, temperature, aggregate stability, bulk density, porosity and hydraulic conductivity. Increasing amounts of rice residues on the soil surface reduce evaporation rates and increased duration of first-stage drying. Soil temperature is influenced through the mechanism of change in radiant energy balance and insulation. The radiation balance is influenced by heating of air and soil, evaporation of soil water and reflection of incoming radiation by surface residue. Soil aggregation refers to the cementing or binding together of several primary soil particles into secondary units. The binding substances include oxides and hydroxides of iron, organic substances directly from plants, decomposition products of crop residues, microbial cells, excretory products of microorganisms and gelatinous substances secreted by earthworms.

2. Soil chemical properties

One of the most important factors determining soil fertility is pH, which may however be influenced strongly by crop residue management. Soil pH can be increased due to the decarboxylation of organic anions on decomposition by microorganisms. Silica rich plant material has the potential of transforming the electrochemical properties of acidic soils that reduces phosphorous fixation; improves base retention and increase the soil pH. Silicates and organics (rice straw) modified iso-electric soils by way of improving the net negative charge, neutralizing acidity of aluminium through manipulation of soil pH and point of zero charge of soil sediments having variable charge contributing materials; reduce phosphorous fixation and increase Si content in plants.

Constraints of using crop residues with conservation agriculture

A series of challenges exist in using crop residues in conservation agriculture. These include difficulties in sowing and application of fertilizer and pesticides, and problems of pest infestation. The conservation agriculture with higher levels of crop residues, usually requires more attention on timings and placement of nutrients, pesticides and irrigation. Lot of improvements have been done in the zero-till seed-cum fertilizer drill system to give farmers a suitable technology. Nutrient management may become complex because of higher residues levels and reduced options for application of nutrients, particularly through manure. Sometimes, increased application of specific nutrients may be necessary and specialized equipments are required for proper fertilizer placement, which contributes to higher costs. Similarly, increased use of herbicides may become necessary for adopting conservation agriculture. Countries that use relatively higher amounts of herbicides are already facing such problems of pollution and environmental hazards. Further limiting factor in adoption of residues incorporation systems in conservation agriculture by farmers include additional management skills, apprehension of lower crop yields, net returns, negative attitudes or perceptions, and institutional constraints. In addition, farmers have strong preferences for clean and good looking tilled fields vis-a-vis untilled shabby looking fields.

Research needs for smart crop residues management with conservation agriculture

Management of crop residues with conservation agriculture is vital for long-term sustainability of Indian agriculture. Hence, burning of residues must be discouraged and utilized gainfully for conservation agriculture in improving soil health and reducing environmental pollution. Several technologies are available for efficient use of crop residues in conservation agriculture. However, they require substantial improvement for large scale adoption by resource poor and low skilled farmers. Happy Seeder seems to be one of the potential technologies for managing crop residues. To facilitate adoption of Happy Seeder, farmers need a smart package and practices for residue retention situations that must guided the farmer for optimum irrigation, fertilizer management, pest management and long-term effects on soil health. Efforts are required to quantify the economic, social and environmental benefits of conservation agriculture based practices under different situations. Some of the research areas which need immediate attention are discussed below.

a. Generation and proper utilization of crop residues

1. Development of region-specific crop residues inventories including total production from different crops, their quality, utilization and amount burnt on-farm, for evolving management strategies. Satellite imageries should be used to estimate the amount of residues burnt on-farm.
2. Assessing the quality of various crop residues and their suitability for off-farm (e.g. animal feed, composting, energy, biogas, biochar and biofuel production) and on farm (e.g. conservation agriculture) purposes.

b. Basic and strategic research for residue management

1. Assessing life-cycle of residue-based conservation agriculture vis-à-vis conventional method of disposing crop residues by burning and other competing uses.
2. Developing crop varieties to produce more root biomass to improve the natural soil resource base.
3. Developing simulation models for prediction of impact of conservation agriculture on crop growth, soil properties, crop yield and farm income.
4. Enhancing decomposition rate of residues for in-situ incorporation.
5. Designing new generation of long-term experiments to study the impact of conservation agriculture on soil health, water and nutrient use efficiency, C sequestration, GHGs emission and ecosystem services.

c. Optimizing competing utilisation of crop residues

1. Analysing the benefit: cost, socio-economic impact and technical feasibility of off and on-farm uses of crop residues.
2. Optimizing residues use that can be retained for conservation agriculture without influencing the crop livestock system, mainly for the regions where residues are the key source of fodder.
3. Assessing the suitability of residue retention/ incorporation in different soil and climatic situations.
4. Quantifying the permissible amount of residues of different crops which can be incorporated/retained, depending on the cropping systems, soil characteristics, and

climate without creating operational problems for the next crop.

5. Assessing benefit: cost and environmental impact of residue retention/incorporation in conservation agriculture vis-à-vis residue burning for short and long term time scales.

d. Appropriate machinery for residue management

1. Development of appropriate farm machinery to facilitate collection, volume reduction, transportation and application of crop residues, and sowing of the succeeding crop under a layer of residues on soil surface.
2. Modifying combine harvester to collect and remove crop residues from field. Twin cutter bar type combine harvester for harvesting of top portion of crop for grain recovery and a lower cutter bar for straw harvesting at a suitable height and windrowing should be developed for proper management of straw.

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Conclusion

The smart management and utilization of crop residues is vital for the enhancement of soil quality and crop productivity under rice-wheat cropping systems of western IGP. Crop residues, usually considered a waste material, if properly managed with innovative technologies can improve soil organic matter dynamics and nutrient cycling, thus creating a rather complimentary environment for plant growth and maintain the sustainability of the system in long term with lower environment footprints.

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