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Crop residues management option for sustainable soil health in rice-wheat system: A review

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Abstract
Rice-wheat system is a dominating cropping system of India and sustainability of it is at risk due to the deterioration of soil health and challenges of climate change. High yields of the irrigated Rice-wheat system have resulted in production of huge quantities of crop residues. Burning of rice straw is common in north-west India causing nutrient losses and serious air pollutions affecting human health. To avoid straw burning, innovations in crop residue management should assist in achieving sustainable productivity and allow farmers to reduce nutrient and water inputs, and reduce risk due to climate change. Crop residues contain significant quantities of plant nutrients and their judicious application will have positive effect on nutrient management in rice wheat system. Long-term studies of the residue recycling have indicated improvements in physical, chemical and biological health of soil. Other plausible option of crop residues management lies in utilizing a portion of surplus residue for producing biochar as soil amendment to improve soil health, increase nutrient use efficiency and minimize air pollution and other i.e. mushroom cultivation as converting of inedible crop residues into valuable food, surface mulch as conservation of soil moisture and weed problem, biofuel and compost production. Residue decomposition in soil substantially increases the soil organic carbon and other nutrient. In this review authors have discussed residue potential and possible options for with efficient management of crop residues in the rice wheat cropping system.

Keywords: Crop residues management, sustainable soil health, rice-wheat system, plant nutrients

Introduction

Crop residues are parts of the plants left in the field after crops have been harvested and threshed. The recycling of crop residues has the advantage of converting the surplus farm waste into useful product for meeting nutrient requirement of succeeding crops. Crop residues are a source of organic C for soil microorganisms and also contribute to plant nutrients. Crop residue retention on the soil surface, substantially reduces run-off and soil erosion and can decrease soil evaporation and land preparation costs (Lal, 1989) [1]. In India there are 500-550 million tones (Mt) of crop residues are produces annually. (MoA, 2012) [2], The Rice Wheat cropping System (RWS) is one of the widely practiced cropping systems in India and about 90% of area is concentrated in the Indo-Gangetic Plains (IGP) (Janaiah and Hossain, 2003) [3]. With the introduction of combine harvesters, more than 75% of the rice area is harvested mechanically in north-western parts of the IGPs.

Most farmers remove wheat straw for feeding the animals. 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. Combine harvester leaves behind a swath of loose rice residues, which interfere with operations of the seed drill used for planting wheat. To avoid these problem farmers burns this crop residue (90-140 Mt annually). From the farmers' point of view, burning may be seen as the most suitable method of disposing of rice straw. It is not only a cost-effective method but it acts as an effective pest control procedure (Dobermann and Fairhurst, 2002) [4]. Gadde *et al.* (2009) [5] estimated that the burning of rice straw contributed 0.05% of the total amount of greenhouse gas (GHG's) emissions in India, which not only lead to loss of huge biomass, i.e. organic carbon, plant nutrients, but also cause adverse effect on soil properties as well as soil flora and fauna. So there is a need to adopt ways and means to manage this valuable resource. In this article, crop residue potential, its management options and soil properties associated with residue management etc are discussed.

Crop residues potential

The Ministry of New and Renewable Energy, Govt. of India (2009) [6] has estimated that about 500 Mt of crop residues are generated every year. The generation of crop residues is highest in Uttar Pradesh (60 Mt) followed by Punjab (51 Mt) and Maharashtra (46 Mt). Among different crops, cereals generate maximum residues (352 Mt), followed by fibers (66 Mt), oilseeds (29 Mt), pulses (13 Mt) and sugarcane (12 Mt). The cereal crops (rice, wheat, maize, millets) contribute 70% while rice crop alone contributes 34% and wheat ranks second with 22% of the crop residues (Fig. 1).

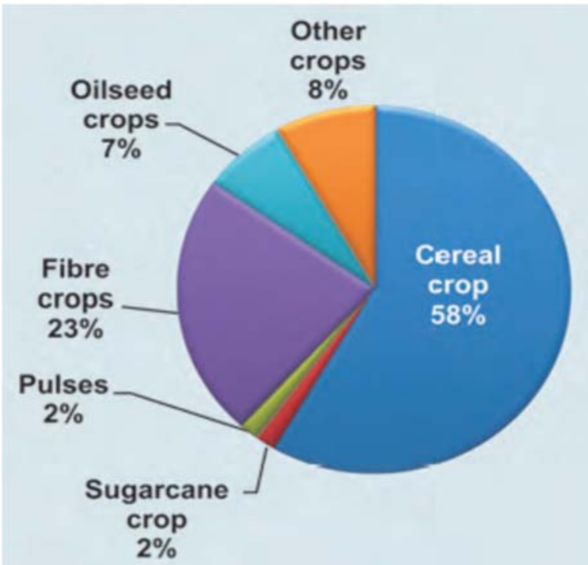

Fig 1: The share of unutilized residues in total residues generated by different crops in India (calculated from MNRE, 2009) [6]

According to Sarkar *et al.* (1999) [7], the rice wheat system accounts for nearly one-fourth of the crop residue production in India. The residue generated is utilized mainly as industrial/domestic fuel, fodder for animals, packaging, bedding, *in situ* incorporation and manuring, thatching and left in field for open burning. However, in case of combine harvesting almost all the residue generated is left in the field, which finally ends up in burning.

Both rice and wheat are exhaustive feeders of nutrients and the double cropping system is heavily depleting the soil of its nutrient content. Dobermann and Fairhurst, (2002) [4] stated that a tone of rice straw contained 5-8 kg of nitrogen. According to Singh and Singh (2001) [8], a rice-wheat sequence that yields 7 t ha^{-1} of rice and 4 t ha^{-1} of wheat remove more than 300 kg N, 30 kg P and 300 kg K ha^{-1} from the soil. Another estimate given by Gupta *et al*. (2002) [9] shows that, 10 t ha^{-1} crop removes 730 kg NPK from the soil that is often not returned to the soil. This may cause mining of soil for major nutrients leading to net negative balance and multi- nutrient deficiencies in crops. This is one of the reasons for the yield decline in the rice-wheat system. Thus, there are urgent needs to manage the residues of these crops for sustainability of soil health and stability of the system.

Crop residues burning

India being an agriculture-dominant country produces more than 500 million tons of crop residues annually and a large portion of these unused crop residues are burnt in the fields primarily to clear the left-over straw and stubbles after the harvest, which interfere with tillage and seeding operation of succeeding crop. Increasing use of combines in harvesting, non availability of labour and high cost of residue removal from the field are main reasons behind burning of crop residues in the fields. The burning of crop residues causes large losses (up to 80 %) of N (Raison 1979) [10], 25% of P and 21% of K (Ponnamperuma 1984) [11] and 4-60% of S (Lefroy *et al.*1994) [12]. This practice also causes significant air pollution and losses of soil microbial mass but also kill the pest and pathogens. Burning of residues results in loss in soil organic matter, which is a visible threat in sustainability of rice wheat system.

Crop residues management options

In India, rice wheat cropping system generates huge quantities of crop residues. Majority of rice and wheat in North West India is harvested by combine harvester leaving residues in the field. The residues of cereal crops are mainly used as cattle feed. Rice straw and husk are used as domestic fuel or in boilers for parboiling rice. Management of rice straw, rather than wheat straw is a serious problem, because there is very little turn-around time between rice harvest and wheat sowing and due to the lack of proper technology for recycling and the higher silica content than other crops. Several management options are available to farmers for the gainful management of crop residues are livestock feed, mushroom cultivation, incorporation, surface retention and mulching, biochar and baling and removing the straw. Farmers use different straw management practices as per the situation.

Crop residues as livestock feed

Traditionally, the crop residues in India are utilized as animal feed such as or by supplementing with some additives. However, crop residues, being unpalatable and low in digestibility, cannot form a sole ration for livestock. The rice straw is considered poor feed for animals due to its high silica content. It differs from other straws in having a higher content of silica (12-16 vs. 3-5%) and a lower content of lignin (6-7 vs. 10-12%). The nutritional value of rice straw can be upgraded by different methods. Physical, chemical and biological treatments have been used to weaken and break down ligno-cellulose bonds in crop residues, thereby increasing their nutritional value (Sarwar *et al.*, 2004) [13]. About 75% of wheat straw is utilized as fodder for animals, chopped in small pieces with the help of special cutting machine though this requires additional operation and investment. Rice straw stems are more digestible than leaves because their silica content is lower; therefore the rice crop should be cut as close to the ground as possible, if the straw is to be fed to livestock. To complete the nutritional requirements of animals, the residues need processing and enriching with urea and molasses, and supplementing with green fodders (leguminous/non-leguminous).

Crop residues as compost

For preparing compost, crop residues are used as animal bedding and then heaped in dung pits. In the animal shed each kilogram of straw absorbs about 2-3 kg of urine, which enriches it with N. The residues of rice crop from one hectare land, on composting give about 3 tons of manure as rich in nutrients as farmyard manure (FYM). The rice straw compost can be fortified with P using indigenous source of low grade rock phosphate to make it value added compost with 1.5 % N, 2.3 % P_2O_5 and 2.5 % K_2O (Sidhu and Beri 2005) [14].

Crop residues as mushroom cultivation

Use of residues in mushroom production represents a valuable conversion of inedible crop residues into valuable food, which despite their high moisture content has two to three times as much protein as common vegetables and an amino acid composition similar to that of milk or meat (Crisan and Sands 1978) [15]. Wheat and rice straws are excellent substrates for the cultivation of *Agaricus bisporus* (white button mushroom) and *Volvariella volvacea* (straw mushroom), two of the four most commonly grown fungi. Straw for *Agaricus* cultivation is usually mixed with horse manure and hay and a very high conversion efficiency of the substrate into fungal bodies is possible (Wuest *et al.* 1987, Maher 1991) [16, 17].

Crop residues as bio-fuel

Biofuel is undoubtedly an important strategy to reduce dependence on fossil fuel. Conversion of ligno-cellulosic biomass into alcohol is of immense importance as ethanol can either be blended with gasoline as a fuel extender and octane-enhancing agent or used as a neat fuel in internal combustion engines. Theoretical estimates of ethanol production from different feedstock (corn grain, rice straw, wheat straw, bagasse and saw dust) vary from 382 to 471 l t^{-1} of dry matter. The technology of ethanol production from crop residues is, however, evolving in India. There are a few limiting steps in the process of conversion of crop residues into alcohol, which need to be improved.

Crop residues as biochar

In the recent year, biochar and crop residues have attracted lots of attention as a viable strategy for maintaining soil health. Biochar is a fine-grained charcoal having high carbon material produced through slow pyrolysis (heating in the absence of oxygen) of biomass. It can potentially play a major role in the long-term storage of carbon in soil. Biochar converted from plant biomass contains a unique recalcitrant form of carbon that is resistant to microbial degradation, therefore can be used as a carbon sequester, when applied to soil (Lemann and Joseph 2009) [18]. In addition, biochar has been shown to reduce greenhouse gas (GHG) from agricultural fields and also improve water quality through its strong absorption nature of contaminants (Spokas *et al*. 2009, Zhang *et al*. 2012) [19, 20]. Nonetheless, the properties of biochar often vary with biomass sources and pyrolysis conditions (Jeong 2015) [21].

Crop residue incorporation

Unlike removal or burning of crop residue, incorporation of straw increases soil organic matter and N, P and K contents in soil. Ploughing is the most efficient residue incorporation method (Ball *et al.* 1990, Christian and Bacon 1991) [22, 23]. Crop residues may be incorporated partially or completely into the soil depending upon methods of cultivation (Dormaar and Carefoot 1996) [24]. Incorporation of rice residues before wheat planting compared to incorporation of wheat straw before rice planting is difficult due to low temperatures and the short interval between rice harvest and wheat planting. The incorporation of Crop Residues in the field is beneficial in recycling nutrients, but leads to temporary immobilization of nutrients (e.g., Nitrogen) and extra nitrogenous fertilizer needs to be added to correct the high C:N ratio at the time of residue incorporation (Singh *et al*. 2005 [25], Singh *et al*. 2008 [26]). This N deficiency caused by decomposer microbial immobilization of available soil and fertilizer nitrogen in the short term. This duration is depends upon decomposition period of crop residue prior to planting next crop, residue quality and soil environment (Singh *et al*. 2005) [25]. The 6 year study of Singh *et al*. (2001) [27] and Singh *et al*. (2004) [28] shows that, the grain yield of wheat and following rice have not been adversely affected by in situ incorporation of rice straw in soil 10, 20, or 40 days before wheat sowing. Rice straw incorporated in wheat did not even show residual effect on succeeding rice crop.

Crop residue as surface mulch

Residue retention on the surface of soil seems to be a better option for conservation of soil and avoiding water losses *by* evaporation. It also reduces the weed seed germination and helps in building of soil microbial populations results in increasing soil organic carbon- a direct indicator of soil health. Zero-till wheat has been adopted in the rice wheat system in the northwest IGP with positive impacts on wheat yield, profitability and resource use efficiency (Erenstein and Laxmi 2008, Ladha *et al.* 2009) [29, 30]. New advance generation seed drill is evolved for this purpose. Sidhu *et al*., (2007) [31] reported that, the Happy Seeder will lead to wider adoption of conservation agriculture. The Happy seeder works well for direct drilling in standing as well as loose residues provided the residues are spread uniformly.

The rice straw mulch increased wheat grain yield, reduced crop water use by 3-11% and improved WUE by 25% compared with no mulch. Mulch produced 40% higher root length densities compared to no-mulch in lower layers (>0.15 m), probably due to greater retention of soil moisture in deeper layers as reported by Chakraborty *et al*. (2008, 2010) [32, 33].

Crop Residue Management and Soil Health

Rice and wheat both is exhaustive feeder of nutrient and due to this excessive nutrient mining of soils is one of the major causes of poor soil health under the Rice-wheat system. The quantities of nutrients removed by rice and wheat are greater than the amount added through fertilizers and recycled. Residues retention improves soil physical (i.e., structure, infiltration rate, plant available water capacity), chemical (i.e., nutrient cycling, cation exchange capacity, soil reaction), and biological (i.e., SOC sequestration, microbial biomass C, activity and species diversity of soil biota) quality (Beri *et al.* 1992, 1995, Singh *et al.* 2008, Singh *et al.* 2005) [34, 35, 26, 36].

Effect on soil physical health

Crop Residue management practices affect soil physical properties such as soil moisture content, aggregate formation, bulk density and soil porosity. Incorporation and/or retention of crop residues in to the soils reduced bulk density and compaction of soils (Bellakki *et al.*, 1998) [37]. The Annual application of 16 t ha^{-1} of rice straw for 3 years decreased bulk density from 1.20 to 0.98 g cm^{-3} in the 0-5 cm layer on a sandy loam. Due to breakdown of aggregates and formation of surface seal by the raindrop impact, causes increase in compaction and reduction in pore proportion of the surface soil resulted in the lower infiltration. Residue retention on the surface solves this problem. Incorporation of crop residues decreased BD and increased infiltration rate, WHC, microbial population, soil fertility as compared to no residue treatment. The residue incorporation with NPK fertilizer resulted in the highest yield, nutrient uptake, improved residual soil fertility and soil microorganism's status (Singh *et al.* 2010) [38].

Effect on soil biological health

Availability of nutrients like N, P, and S is particularly dependent upon soil microbial biomass (SMB) and microbial activity, which in turn depend on the supply of organic substrates in soil. The population of soil flora and fauna is positively correlated with the phyto-biomass present in soil. Beri *et al.* (1992) [35] and Sindu *et al*. (1995) [39] observed that soil treated with crop residues held 5-10 times more aerobic bacteria and 1.5-11 times more fungi than soil were either burn or removed. The study of Verhulst *et al.* (2009) [40] reveled that, soil microbial biomass (C and N) decreased with decreasing amount of residue retained on the soil surface in the zero till treatments of both rainfed and irrigated long term trial. The soil microbial biomass reflects the soil's ability to store and cycle nutrients (C, N, P and S) and organic matter and plays an important role in physical stabilization of aggregates. Crop residues are also known to enhance nitrogen fixation in soil by asymbiotic bacteria (*Azotobacter chrococcum* and *A. agilis*). Due to increase in soil microbial population the activity of soil enzymes responsible for conversion of unavailable to available form of nutrient also increases.

Effect on soil chemical health

The pH of the soil is a determining factor of soil fertility greatly influenced by the crop residues incorporated in the soil. Long-term straw application will build soil organic matter level and N reserves, and also increase the availability of macro- and micro-nutrients. The 11 year filed study conducted on loamy sand soil by Beri *et al.* (1995) [35], it has been seen that the incorporation of residues of both crops in rice wheat system as increased the total P available P and K content, in the soil over the removal of residues. Gupta *et al.* (2007) [41] reported from the 3 year study that the inorganic and organic P, reduced P sorption, and increased P release increases with the incorporation of crop residue over straw burned. About 50-80% of micronutrient (Zn, Fe, Cu and Mn) taken up by rice and wheat crops can be recycled through incorporated residue. Crop residue influences availability of micronutrients such as zinc and iron in rice (Singh *et al*. 2005 and Gupta *et al*. 2007) [25, 41].

Residue characteristics as well as soil and crop management factors also affect residue decomposition. Under optimum temperature and moisture conditions, N immobilization can last 4-6 weeks. Soil microbial biomass (SMB) is affected by the residue management practices. Many workers reported a decline in microbial biomass when residues are burnt. Residue incorporation results more microbial activity than residue removal or burning.

Conclusions

The rice-wheat cropping system is the most intensive production system in the country. It occupies a dominating share of total cultivable land in India. The recycling of its residues has the great potential to return a considerable amount of plant nutrients to the soil. Particularly the yield stagnation consequent upon the declining soil organic carbon is a major threat to this system. Therefore it is a great challenge to the agriculturists to manage rice residues effectively and efficiently for enhancing sequestration of carbon and maintaining the sustainability of production. Every management options have its advantages as well as disadvantages. It depends possible on given set of soil, climate and crop management conditions, compatible with available machinery and socially and economically acceptable. To avoid residues burning in rice wheat cropping system it needs to review and upgrade the technology with mechanized harvester for sustainable utilization of residues. Location and soil condition specific conservation tillage technology may be adopted. Research has shown that diversification of the rice-wheat cropping system is also essential. If rice residues are managed properly, then it can warrant the improvements in soil physical, chemical and biological properties and sustain productivity of rice-wheat cropping system.

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