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Recycling and management of crop residues for sustainable soil health in climate change scenario with farmer's profit as frontline moto

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Abstract
In sustainable agriculture, one of the most relevant objective is to maintain and restore the soil fertility. Continuous cropping of the land with inorganic fertilizer alone causes decline in soil organic matter and loss of inherent fertility. Global warming and its consequences are amongst the most serious problems of the present century. Agricultural crop residue burning contribute towards the emission of greenhouse gases (CO2, N2O, CH4), air pollutants (CO, NH3, NOx, SO2, NMHC, volatile organic compounds), particulates matter and smoke thereby posing threat to human health. Total amount of residue generated in 2008–09 was 620 Mt out of which ~15.9% residue was burnt on farm. Rice straw contributed 40% of the total residue burnt followed by wheat straw (22%) and sugarcane trash (20%).Conservation agriculture and recommended management practices (RMPs) collectively are helpful to offset part of the emissions due to unscientific agricultural practices. An intensive agricultural practice during the post green revolution era without caring for the environment has supposedly played a major role towards enhancement of the greenhouse gases. Due to increase in demand for food production the farmers have started growing more than one crop a year through repeated tillage operations using conventional agricultural practices. This has led to the renewed interest in use of organic manures as sources of soil organic matter. Among the available organic sources, crop residues are the most important sources of nutrients to the crop in addition to improving soil health. The application of organic matter alone to soil is not a complete substitute for inorganic fertilizer and vice-versa and their roles are complementary to each other. The knowledge on nutrient release from crop residues and their influence on physical, chemical and biological properties would be very much helpful in proper management of crop residues. This review focuses on soil properties as influenced by crop residue management.

Keywords: Crop residues, Soil properties, Nutrient availability and biological activity.

Introduction

Agricultural residues are the biomass left in the field after harvesting of the economic components i.e., grain. Large quantities of crop residues are generated every year, in the form of cereal straws, woody stalks, and sugarcane leaves/tops during harvest periods. Processing of farm produce through milling also produces large amount of residues. These residues are used as animal feed, thatching for rural homes, residential cooking fuel and industrial fuel. However, a large portion of the crop residues is not utilized and left in the fields. The disposal of such a large amount of crop residues is a major challenge. To clear the field rapidly and inexpensively and allow tillage practices to proceed unimpeded by residual crop material, the crop residues are burned in situ. Farmers opt for burning because it is a quick and easy way to manage the large quantities of crop residues and prepare the field for the next crop well in time. Agricultural residues burning may emit significant quantity of air pollutants like CO2, N2O, CH4, and emission of air pollutants such as CO, NH3, NOx, SO2, NMHC, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) and particulate matter like elemental carbon at a rate far different from that observed in forest fire due to different chemical composition of the crop residues and burning conditions (Zhang *et al*., 2011, Mittal *et al*., 2009). Several researchers have estimated the emission of different species from crop residue burning using IPCC factors, but they have covered only few gaseous pollutants (N2O, CH4, NOx, and SO2) (Venkataraman *et al*., 2006; Sahai *et al*., 2007) [22]; or from a specific area and crop (Badrinath *et al*., 2006; Sahai *et al*., 2007) [3, 22]. The review focuses on studies examining physical, chemical and biological properties of agricultural soils in subtropical India where 70 per cent smallholder farmers adopted imbalance fertilizers and climate changes affected levels of soil degradation threaten the sustainability of agricultural systems.

Management practices relating to crop residue

The amount of crop residue generated was estimated as the product of crop production, residue to crop ratio and dry matter fraction in the crop biomass. The residue to grain ratio varied 1.5–1.7 for cereal crops, 2.15–3.0 for fiber crops, 2.0–3.0 for oilseed crops and 0.4 for sugarcane. Total amount dry crop residue generated by nine major crops was 620.4 Mt namely cereals (Rice, Wheat, Maize, Sorghum, Bajra, Ragi and small millets), oilseeds (groundnut and rapeseed mustard), fibres (Jute, Mesta and Cotton) and Sugarcane. Generation of cereal crop residues was highest in the states of Uttar Pradesh (72 Mt) followed by Punjab (45.6 Mt), West Bengal (37.3 Mt), Andhra Pradesh (33 Mt) and Haryana (24.7 Mt). Uttar Pradesh contributed maximum to the generation of residue of sugarcane (44.2 Mt) while residues from fibre crop was dominant in Gujarat (28.6 Mt) followed by West Bengal (24.4 Mt) and Maharashtra (19.5 Mt). Rajasthan and Gujarat generated about 9.26 and 5.1 Mt residues, respectively from oilseed crops. Among the different crop categories 361.85 Mt of residue was generated by cereal crops followed by fibre crops (122.4 Mt) and sugarcane (107.5 Mt). The cereals crops generated 58% of residue while rice crop alone contributed 53% and wheat ranked second with 33% of cereal crop residues. Fibre crops contributed 20% of residues generated with cotton ranking first (90.86 Mt) with 74% of crop residues. Sugarcane residues generated 17% of the total crop residues. The oilseed crops generated 28.72 Mt of residue annually. Our estimates are in line with the reports in literature (MNRE, 2009, Pathak *et al*., 2010). According to IPCC the 25% of the crop residues are burnt on farm. In the present study the fraction of crop residue subjected to burning ranged from 8–80% for rice paddies across the states. In the states of Punjab, Haryana and Himachal Pradesh 80% of rice straw was burnt in situ followed by Karnataka (50%) and Uttar Pradesh (25%), which can be attributed to the mechanized harvesting with combine harvesters (Gupta *et al*., 2003). At present 75–80% of rice wheat area in Punjab is harvested with combines. Approximately 23% wheat straw was taken as fraction burnt in the states of Haryana, Himachal Pradesh, Punjab and Uttar Pradesh and for rest of the states it was 10%. For sugar cane trash it was considered that 25% of the trash is burnt in the fields. Highest amount of cereal crop residues were burnt in Punjab followed Uttar Pradesh and Haryana. Uttar Pradesh contributed maximum to the burning of sugarcane trash followed by Karnataka. Oil seed residues were burnt in Rajasthan and Gujarat while burning of fiber crop residue was dominant in Gujarat (28.6 Mt) followed by West Bengal (24.4 Mt) Maharashtra and Punjab. Among the different crop residue major contribution (93%) was from rice (43%), wheat (21%) and sugarcane (19%). Similar results were also reported by Sahai *et al*., (2011).

Emission of gaseous and aerosol species

According to Yevich and Logan (2003) 91, 4.1, 0.6, 0.1 and 1.2 Tg/yr of CO2, CO, CH4, NOx and total particulate matter were emitted due to burning of crop residues in India in the year 1985. Emissions from open biomass burning over tropical Asia were evaluated during seven fire years from 2000 to 2006 by Chang *et al*., (2010) [7]. Venkataraman, (2006) have inventoried the emissions from open biomass burning including crop residues in India using Moderate Resolution Imaging Spectro radiometer (MODIS) active fire and land cover data approach. Badrinath *et al*. (2006) [3] estimated the greenhouse gas (GHG) emissions from rice and wheat straw burning in Punjab during May and October 2005 and suggested that emissions from wheat crop residues in Punjab are relatively low compared to those from paddy fields. Sahai *et al*., (2007) [22] have measured the emission of trace gas and particulate species from burning of wheat straw in agricultural fields in Pant Nagar. Sahai *et al*. (2011) have estimated that burning of 63 Mt of crop residue emitted 4.86 Mt of CO2 equivalents of GHGs 3.4 Mt of CO and 0.14 Mt of NOx.

Loss of residues nutrient

Burning of crop residue not only leads to pollution but also results in loss of nutrients present in the residues. The entire amount of C, approximately 80–90% N, 25% of P, 20% of K and 50% of S present in crop residues are lost in the form of various gaseous and particulate matters, resulting in atmospheric pollution (Ponnamperuma, 1984). In the present study the amount of different nutrients lost due to on farm burning of rice straw, wheat straw and sugarcane trash were also estimated. Maximum loss of nutrient was due to sugarcane trash burning followed by rice and wheat straw. Burning of sugar cane trash led to the loss of 0.84 Mt, rice residues 0.45 Mt and wheat residue 0.14 Mt nutrient per year out of which 0.39 Mt was nitrogen, 0.014 Mt potassium and 0.30 Mt was phosphorus.

Bulk density and total porosity

A long-term fertilizer experiment conducted by Chaudhary *et al*. (2017) in rice-wheat cropping system at Punjab Agricultural University, Punjab on sandy loam soil revealed that the incorporation of straw + NPK increased total soil porosity (46.3%) and decreased the bulk density (1.42 Mg m-3) upto 0-15 cm when compared to 100% NPK treated plots (43.1%, 1.51 Mg m-3, respectively). An experiment conducted on utilization of crop residues as compost for improving soil physical properties revealed that maize stover compost recorded maximum total porosity (49.05) followed by rice compost (47.87%) over control (43.23%) (Baru.2016).

Soil organic carbon

Soil organic carbon (SOC) is naturally removed from the soil through soil heterotrophic and autotrophic respiration, where carbon (C) is released as CO2. However, human activities such as land-use changes, in particular conversion to agricultural fields and removal of crop residues and direct feeding to livestock, release even greater amounts of C into the atmosphere as CO2 (Prentice *et al*., 2001). Agricultural practices disturb the SOC pool, which represents a large potential source of greenhouse gasses; soil C loss can thus lead to lower soil quality and pressure on sustainable crop production and food security (Lal, 2007) [20]. Paustian *et al*., 1997a revealed that crop residue contributes directly to SOM and its decomposition is the initial stage in the humus formation process leading to C storage. Govaerts *et al*., 2009b [14] reported that crop residue retention is key to increasing and/or maintaining SOC levels; however, its effect may be controlled by soil type, climate and management factors. Yadvinder-Singh *et al*. (2004) [24] observed that organic C content in soil increased from 0.41 to 0.59 g/kg soil after 7 years of rice residue incorporation before sowing wheat. The percent increase in organic carbon content is greater on sandy loams with lower initial organic carbon content than on silt loams (Yadvinder-Singh *et al*., 2009). Thus recycling of straw can increase C accumulation in the soil, which can be advantageous in terms of both global warming and soil fertility.

pH and Electrical Conductivity (EC)

The lowest soil pH (7.70) was observed with soil incorporation of wheat straw and green manure in alluvial soil due to the production of organic acids during decomposition. Electrical conductivity of the soils was not significantly influenced by the incorporation of organics (Dhar *et al*., 2014). Shahrzad *et al*. (2014) reported an increase in pH and electrical conductivity of soil with incorporation of crop residues. Anilkumar *et al*. (2012) reported that the application of FYM, wheat straw and green manure along with inorganic fertilizers decreased the soil pH and soluble salt concentration as compared to the fertilizers alone.

Nutrient availability

Dhiman *et al*., (1999) reported that organic carbon; available P and K were highest where an additional FYM application was made. Jaiswal and Singh, 2001 found that Nitrogen at 120 kg N ha-1 increased the nitrogen uptake by 41.9 and 34.8 per cent over 60 kgN ha-1 in grain and straw, respectively. Higher uptake of N might be due to better established roots, better plant growth and yield under increased N level. Zibilske *et al*., (2002) found that Residue retention has been found to increase the concentration of P in the top soil. This can be attributed to redistribution of P mined from the lower soil layers. Laroo *et al*. (2007) revealed that N uptake was significantly influenced due to different levels of N application. Based on the total N uptake (grain + straw), there was 49.9, 63.9 and 70.4 per cent increase in N uptake over the control with 50, 100 and 150 kg N ha-1,respectively. Kukal *et al*. (2009) also observed that SOC concentration in the 0–60 cm soil profile was higher under FYM application (1.8 to 6.2 g kg–1) followed by NPK application (1.7 to 5.3 g kg–1) when compared to control plots. Application of bio-inoculants and retention of crop residues conjointly help maintain C and N balance in soil and enhance labile C pool in rice-legume rice cropping systems (Thakuria *et al*., 2009).

Surface runoff and soil loss

Conversion from conventional to zero tillage, reduced erosion (Wright *et al*., 1999) and avoided surface sealing because of crop residue cover on the surface and higher aggregate stability under zero tillage, which protected soil fertility (Tebrugge and During, 1999; Rasmussen, 1999). Flat residues as a mulch on the soil surface act as a barrier restricting soil particles emissions from the soil surface and also increasing the threshold wind speeds for detaching these particles. It has been reported that standing residues are more effective than flat residues in reducing erosion by reducing the soil surface friction velocity of wind and intercepting the saltating soil particles (Hagen, 1996). (Bertol *et al*., (2007) [6] revealed that residue retention on the soil surface can also provide physical soil protection against water and soil loss. In addition, crop residues cause a lower sediment load in surface runoff during rainfall. The protective influence of residue retention on the surface was further emphasized by the high runoff and soil loss levels in the disk-harrow treatments with 2 and 4 t ha-1 of soybean residue, which were incorporated rather than left on the soil surface (Panachuki *et al*., 2011). Araya *et al*., (2011) found that after 3 years of wheat (Triticum sp.)-teff (Eragostis tef) rotation, soil loss and runoff were significantly lower in permanent raised beds with 30% standing stubble compared to furrows without surface residue and CT without surface residue.

Soil temperature

Prihar and Arora (1980) observed that Straw mulch reduces the amount of radiation reaching and leaving the soil surface, and therefore reduces the maximum soil temperature and increases the minimum temperature. The effect of straw mulch on soil temperature can be an advantage where soil temperature is above the optimum for germination and growth, and a disadvantage where temperatures are lowered below the optimum (Lal, 1989). Green and Lafond (1999) reported the heat advantage of tillage and residue management and highlighted that surface residues with no-till system helped in regulating the soil temperature and they noticed that the soil temperature (5cm soil depth) with residue removal and conventional till was 0.290C lower during the winter than that of no-till and surface retained residues whereas the soil temperature during summer was 0.890C higher under conventional till than no-till surface retained residue situation. Gupta *et al*., (1983) also found that the difference between zero tillage with and without residue cover was larger than the difference between conventional tillage (mouldboard ploughing) and zero tillage with residue retention. Both mouldboard ploughing and zero tillage without residue cover had a higher soil temperature than zero tillage with residue cover, but the difference between mouldboard ploughing and zero tillage with residue cover was approximately one-third the difference between zero tillage with and without residue.

Microbial activity

The intensity of soil tillage strongly influences earthworm populations and, by their activity, the amount of biopores. Earthworms support decomposition and incorporation of straw. Zero tillage proved to be more efficient than the other tillage systems (reduced and conventional tillage) in the conservation of organic carbon and microbial biomass carbon at the soil surface depth (0-5cm) as reported by Costantini *et al*., (1996) [9]. Radford *et al*., (1995) also showed there was a fourfold increase in earthworm numbers with zero tillage as compared to conventional tillage. Wuest *et al*., (2005) observed that Residue retention can have a varying effect on earthworms, however, depending on their ecological niche, as tillage may benefit endogeic (horizontal-burrowing) earthworms if residue is incorporated into the soil, providing a food source. Ha *et al*., (2008) reported that different residues resulted in different levels of POM, which cultivate distinct microbial communities.

Concerns and trade-offs of implementing CA

According to Chivenge *et al*., (2007) [8] the increase in soil organic matter with residue retention is higher on sandy soils than clay soils while reduction in soil organic matter with tillage is higher on clay soils than on sandy soils. Morris *et al*., (2010) revealed that conservation tillage is evolving practice to reduce the risk of soil erosion, conserve soil organic matter and improve soil structural stability. CA has been promoted and practiced as solution for agricultural sustainability problems resulting from soil erosion and fertility decline (Govaerts *et al*., 2009) [15] and reduce farmers' vulnerability to drought, and address low draught power ownership levels (Mashingaidze *et al*., 2012). Hobbs and Govaerts, (2010) [18] observed that CA results in improved soil physical and biological health, better nutrient cycling and crop growth as well as increasing water infiltration (Ranging from 45 to 87% increase in infiltration rate with CA compared to conventional practices) and soil penetration by roots, which allows crops to better adapt to lower rainfall and make better use of water. Akinnifesi *et al*., (2011) [1] reported that some fertilizer trees can add up to 60 kg N/ha/yr, reduce the need for mineral fertilizers by 75% and substantially increase crop yield. In some conditions (East and Southern Africa), the use of fertilizer trees can double maize yield and, thus, enhance profit and net returns Akinnifesi *et al*., (2011) [1].

In conclusion, the challenge now is how to rapidly mobilize this knowledge so that it can be applied to restore already affected areas or to prepare rural areas predicted to be hit by climate change. For this horizontal transfer to occur quickly, emphasis must be given to involving farmers directly in the extension of innovations through well – organized farmer- to-farmer networks. The focus should be on strengthening local farmers self help group for farmers participatory research and problem solving capacities to enhance agricultural resiliency to climate change must make effective use of traditional skills and knowledge thus improving prospects for community empowerment and self reliant development in the face of climate variability.

Expectations

Based on discussions with smallholder farmers, the following expectations will have to be met to make the CA effort a satisfying experience for them:

- Small holder farmers will have to be made equally aware and be able to effectively participate in needed efforts and not be isolated in its introduction and scaling up.
- They should be able to carry out the switch to CA in a manner affordable to them. If CA can help in savings on costs incurred on account of non-tillage as an example, the same would be even better offering them benefits in the short term as well.
- A strong support system will need to be positioned to transfer knowledge through field demonstrations and also reduce their vulnerability to build confidence as the process of switchover is adopted.
- With effects of climate change adding to their existing vulnerability, reducing the impact of such an eventuality can greatly reduce risk for them and it will make sense for them to internalize the advantage offered by CA in this regard.

Key Issues

Issues as seeming to emerge with efforts moving to the field in a scaled up manner will be:

- Adaptability of equipment (seeding and harvesting) for effective deployment on small fields. Once equipment is ready, making it available and affordable across the regions will hold the key to its effective deployment.
- Farmers in a region will need to be provided with viable cropping system alternatives.
- Making knowledge available for needs of awareness and extension will be a challenge given poor reach today.
- Demonstration on farmer plots with involvement of others on an observation basis will be a useful tool to improve adoption.
- Develop technologies for sustainable intensification and diversification of the rice– wheat systems, including tillage and crop establishment options for growing rice and wheat in sequence in a systems perspective.
- Help to disseminate promising technologies for scaling up among in smallholders farming community in different regions of the subtropical India so as to produce more food

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