

Review Article

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Crop Residue Management and Soil Health with Changing Climate in Smallholders Farming: A Subtropical Indian Perspective

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ABSTRACT

There are 115 million operational holdings in the country and about 80 % are marginal and small farmers. To fulfill the basic needs of house hold including food, feed, fodder, fiber, etc. warrant an attention about bio intensive cropping system (BICS). 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, NO_x, 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. The feasibility of conservation agriculture for recuperating degraded soils and increasing crop yields of the smallholder farming systems in the subtropics is discussed. It is clear that the biggest obstacle to improving soils and other ecosystems through conservation agriculture in these situations is the lack of residues produced and the competition for alternate, higher value use of residues. This limitation, as well as others, point to a phased approach to promoting conservation agriculture in these regions and careful consideration of the feasibility of conservation agriculture in different agro-ecological conditions.

Keywords

Crop residue;
soil health;
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Introduction

India is an agrarian country and generates a large quantity of agricultural wastes. This

amount will increase in future as with growing population there is a need to increase

the productivity also. 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, NO_x, 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, NO_x, and SO₂) (Venkataraman *et al.*, 2006; Sahai *et al.*, 2007); or from a specific area and crop (Badrinath *et al.*, 2006; Sahai *et al.*, 2007). Burning of crop residues also causes nutrient and resource loss. This article reviews the literature on the influence of crop residue management and trade-offs on soil quality and health in order to examine its advantages and limitations in cereal-based agro-

ecosystems. 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

On farm burning of 98.4 Mt of crop residues led to the emission of 8.57 Mt of CO, 141.15 Mt of CO₂, 0.037 Mt of SO_x, 0.23 Mt of NO_x, 0.12 Mt of NH₃ and 1.46 Mt NMVOC, 0.65 Mt of NMHC, 1.21 Mt of particulate

matter for the year 2008–09 . CO₂ accounted for 91.6% of the total emissions. Out of the rest (8.43%) 66% was CO, 2.2% NO, 5% NMHC and 11% NMVOC. Burning of rice straw contributed the maximum (40%) to this emission followed by wheat (22%) and sugarcane (20%). Highest emissions were from the IGP states with Uttar Pradesh accounting for 23%, followed by Punjab (22%) and Haryana (9%).

Burning of agricultural residues, resulted in 70, 7 and 0.66% of C present in rice straw as CO₂, CO and CH₄, emission respectively, while 20, 2.1% of N in straw is emitted as NO_x and N₂O, respectively, and 17% as S in straw is emitted as SO_x upon burning (Carlson *et al.*, 1992).

According to Yevich and Logan (2003) 91, 4.1, 0.6, 0.1 and 1.2 Tg/yr of CO₂, CO, CH₄, NO_x 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). Venkataraman, (2006) have inventoried the emissions from open biomass burning including crop residues in India using Moderate Resolution Imaging Spectroradiometer (MODIS) active fire and land cover data approach. Badrinath *et al.* (2006) 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) 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 NO_x.

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

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). 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 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) 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. On the basis of soil C values and the amount of C applied, 12–15% of paddy straw-C incorporated into the soil was sequestered by the soil after 7 years (Yadvinder-Singh *et al.*, 2004). In another study (Yadvinder-Singh *et al.*, 2009), C sequestration in soil from straw mulch after 2.5 years was about 25% on both sandy loams and silt loams. The amount of C sequestration from straw incorporation under conventional tillage was lower at 17%.

Climatic factors that influence decomposition rates can also affect the potential amount of SOC accumulation with residue surface retention vs. incorporation. Kushwaha *et al.*, 2001 found that in Varanasi, India, with high temperatures and decomposition rates, SOC and total N were highest under minimum tillage with residue retained on the surface compared to incorporation. Management factors such as incorporating by tillage or leaving crop residue on the soil surface can additionally influence the effect of crop residue retention on SOC in the soil profile. Conventional tillage is usually considered responsible for C losses by increasing decomposition rates (Reicosky, 2003). Tillage disturbs soil structural stability (Kay, 1990) and redistributes organic matter, influencing microbial activity at the soil surface that releases carbon (Carter, 1986). In this way, cultivation has led to a 30–50% reduction in

pre-cultivation SOC levels in agricultural soils (Schlesinger, 1985). Although several studies have observed higher SOC content under no-tillage with residue retention (Govaerts *et al.*, 2009b), this practice concentrates C on the soil surface (Baker *et al.*, 2007). In contrast, tillage affects the distribution of SOC in the soil profile by incorporating residues in the soil, thus increasing SOC in deeper layers (Gál *et al.*, 2007; Jantalia *et al.*, 2007). Wright *et al.*, 2007 observed that Soil organic C and total N were highest at 0–5 cm and decreased with depth to 30–55 cm, below which few tillage or cropping sequence effects were observed. The depth distribution of SOC and total N indicated treatment effects below levels of the maximum tillage depth, while intensive cropping increased SOC and total N for NT compared to CT to a greater depth than for monoculture wheat.

Dong *et al.*, 2009 found that SOC content for the conventional tillage without surface residue, rotary tillage with incorporated chopped residue, no-tillage with surface chopped residue, and no-tillage with standing residue treatments was highest in the 0–5 cm layer, but decreased with depth up to 30 cm. Under the conventional tillage with residue treatment, SOC content was highest in the 5–10 cm layer below the surface. Moldboard ploughing is usually shown to decrease C stocks, but in this study there was a significant increase in the conventional tillage with residue treatment, emphasizing once more the variable effect on SOC caused by crop residue management practices. Ngwira *et al.*, (2012) revealed that SOC and SON in ZT fields were 44 and 41 % (4 years ZT) and 75 and 77 % (5 years ZT) higher, respectively, than CT plots. MB-C and MB-N in ZT fields were 16 and 44 % (4 years ZT) and 20 and 38 % (5 years ZT) higher, respectively, than CT plots. The higher SOC and MB-C content in the ZT fields resulted in 10, 62, 57 %

higher C mineralization rate in ZT plots of 3, 4 and 5 years of loamy sand soils and 35 % higher C mineralization rate in ZT plot of 2 years than CT of sandy loam soils in undisturbed soils. No-till improves soil quality (soil function), carbon, organic matter, aggregates, protecting the soil from erosion, evaporation of water, and structural breakdown (Araya *et al.*, 2012).

A reduction in tillage passes helps prevent the compaction of soil. Recently, researchers found that no-till farming makes soil much more stable than ploughed soil (Li *et al.*, 2011). In addition, No-till stores more carbon in the soil and carbon in the form of organic matter is a key factor in holding soil particles together. Crop residues left intact help both natural precipitation and irrigation water infiltrate the soil where it can be used (Friedrich *et al.*, 2009). The crop residue left on the soil surface also limits evaporation, conserving water for plant growth (Thierfelder and Wall, 2009). Paudel *et al.*, (2014) observed that soil organic carbon buildup was affected significantly by tillage and residue level in upper depth of 0-20 cm but not in lower depth of 20-40 cm. Higher SOC content of 19.44 g kg⁻¹ of soil was found in zero tilled residue retained plots followed by 18.53 g kg⁻¹ in permanently raised bed with residue retained plots. Whereas, the lowest level of SOC content of 15.86 g kg⁻¹ of soil were found in puddled transplanted rice followed by wheat planted under conventionally tilled plots.

Cation exchange capacity

Govaerts *et al.* (2007c) observed that after five years, CEC increased in the topsoil when residues were retained compared to soils without residue, but there was no difference in the 5–20 cm layer. In West Africa, Lal (1997a) observed that while residue retention increased CEC both when residues were

retained on the surface and incorporated, the increase in CEC was greatest when residues were retained on the surface. Kumar *et al.*, 2015 reported that the cation exchange capacity (CEC) was also increased due to tillage crop establishment. The highest CEC increase (10.3%) was found in T₁ followed by T₅ (4.2%) and T₃ (1.4%). Treatment T₇ showed the lowest increase of CEC from the experimentation. The large loss of aggregate stability for the zero-till system is of particular concern, as it suggests that the increased aggregate stability of surface soil under no-till is due to surface residue rather than an intrinsic property of zero-tillage. Mohanty *et al.*, 2015 observed that adoption of MT enhanced the CEC of soils even within a short span of two years and the increase was in the tune of 11.2% over CT system {26.2 c mol (p+) kg⁻¹}. Ben Moussa-Machraoui *et al.*, 2010 found greater organic matter accompanied by a corresponding increase in CEC under no tillage compared to conventional tillage.

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) 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. This was explained by increased aggregate stability and the mulching effect of the standing stubble, consistent with the results of Gebreegiabher *et al.*, (2009) and Oicha *et al.*, (2010).

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.

Yadvinder-Singh *et al.*, (2010) reported that the use of crop residues as a mulching material under optimal conditions has been found beneficial as it reduces maximum soil temperature and conserves water. The effectiveness of mulch to reduce soil water evaporation depends on the soil type, rainfall pattern and evaporative demand. Gathala *et al.*, 2011 reported the soil thermal regime in three contrasting treatments T₁ (CT-TPR/CT-DSW), T₃ (Bed-DSR/Bed-DSW), and T₅ (ZT-DSR/ZTDSW) and found that at minimum soil (5-cm depth) temperature at 0700 and maximum at 1500 h varied between 6 and 16⁰C and 11 to 26⁰C, respectively. The differences in minimum and maximum temperatures in different treatments ranged between 0.6 and 7.2⁰C. At 0700 h, soil temperature was generally higher in T₅ than T₁ in the first 16 wk, and thereafter soil temperature remained unchanged; whereas at 1500 h, the trend was reversed between the two treatments. On the other hand, T₃ closely followed T₁ for both minimum (at 0700 h) and maximum temperatures (at 1500 h). The data indicate that diurnal temperature fluctuation at the soil surface was consistently lower in the ZT flat bed system (T₅) than in the CT flat bed (T₁) and raised bed planting system (T₃).

Verhulst *et al.*, (2010a) found that Retaining residues on the soil surface has been noted to decrease daytime soil temperature Hatfield *et al.*, (2011) observed that in the U.S., there is a variation among crops in their response to CO₂, temperature and precipitation changes, along with regional differences in predicted climate. Gupta *et al.*, 2010 revealed that under zero till drilling with residue retained keeps canopy temperature lower by 1 to 1.5⁰C during grain filling stage (cooling due to transpiration) owing to sustained soil moisture availability to the plants for reasons enumerated previously facilitating in better grain filling. In absence of residue retention,

farmers have no option but to match last irrigation with grain filling if terminal heat stress penalty is to be avoided. Singh *et al.*, (2011) revealed that straw mulch in wheat lowered the maximum soil temperature by about 2.0° C and increased the minimum soil temperature by about 1.0° C during the first 21 days after sowing of wheat. Yap *et al.*, (2012) revealed that according to the Food and Agriculture Organization, global mean surface temperature is projected to rise between 1.8°C to 4.0°C by 2100. The poor and the landless in small farm systems are the most vulnerable to the effects of climate change. This is because of their lack of adaptation, limited capacity for mitigation, inadequate access to new technologies and services that can reduce risks and promote increased adaptation to heat stress for example in cropping patterns. The effects of climate change on land use and livelihood systems. The effects are serious and wide ranging, and cause *inter alia* reduced soil moisture, increased water stress and reduced yields from cropping systems; increased heat stress on animals; overstocking of heat tolerant animals; reduced biodiversity; and reduced ecosystem services. The resultant trend will have negative impacts and a shift out of agriculture.

Naresh *et al.*, 2015 found that soil temperature at transplanting zone depth (5 cm) during rice crop establishment were lowered in treatments ZT-TPR (T₁) and RT-TPR (T₂) by 3.6 and 2.7°C compared to the treatment NBed-TPR (T₃), respectively. Zero tillage reduced the impact of solar radiation by acting as a physical barrier resulting in lower soil temperature than the plough soil. The increasing trend in soil temperature for narrow raised beds. This was probably due to exposure of more surface area to the incident solar radiation in narrow raised beds than in flat conventional treatments. T₃ and WBed-TPR (T₄) recorded higher soil temperature

(mean of 38.4 V/S37.7°C) compared to the flat treatments T₁, T₂ and CT-TPR (T₅) at 15DAT. Soil temperature remained similar when compared separately among flat layout and raised bed treatments.

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). Radford *et al.*, (1995) also showed there was a fourfold increase in earthworm numbers with zero tillage as compared to conventional tillage. Increased earthworm activity in no-till treatments was also reported by Tebrugge *et al.*, (1999) and Rasmussen (1999). Spedding *et al.*, (2004) found that residue management had more influence than tillage system on microbial characteristics, and higher SMB-C and N levels were found in plots with residue retention than with residue removal, although the differences were significant only in the 0-10 cm layer. 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. The effect of crop residue on earthworms and other soil fauna can thus vary depending on tillage frequency, plow depth, residue incorporation, and crop residue type, amount and quality (Eriksen-Hamel *et al.*, 2009). Ha *et al.*, (2008) reported that different residues resulted in different levels of POM, which cultivate distinct microbial communities.

James *et al.*, 2010 revealed that long-term no-tilled soils have significantly greater levels of microbes, more active carbon, more SOM, and more stored carbon than conventional tilled soils. A majority of the microbes in the soil exist under starvation conditions and thus they tend to be in a dormant state, especially in tilled soils. Wang *et al.*, (2012) reported increased microbial biomass carbon with crop residue application in comparison to no crop residue application. Moharana *et al.*, (2012) revealed that the highest values of TOC (11.48 g kg^{-1}) and WBC (7.86 g kg^{-1}) were maintained in FYM treated plot, while the highest values of LBC (1.36 g kg^{-1}) and MBC (273 mg kg^{-1}) were found in FYM + NPK. The magnitude of change in pools of SOC in sub-surface (15–30 cm) soil was low as compared to the surface soil (0–15 cm). Significant increase in all the pools of SOC in FYM treated plots indicates the importance of application of organic manure like FYM in maintaining organic carbon in soil.

Zhu *et al.*, (2014) found that Soil TOC and labile organic C fractions contents were significantly affected by straw returns, and were higher under straw return treatments than non-straw return at (0–7, 7–14 and 14–21 cm) depths. Kumar *et al.*, 2016 reported that application of fertilizer N, P; farmyard manure (FYM) and crop residues enhanced total organic C from 4.5 g kg^{-1} in control to 6.4 g kg^{-1} in surface layer and from 3.3 to 4.4 g kg^{-1} in subsurface layer after 4 years in CA practices. Other soil health attributes like labile C and N fractions such as water-soluble C (38.9 mg kg^{-1}), particulate (1483 mg kg^{-1}) and light fraction (209 mg kg^{-1}) organic matter, potentially mineralizable N ($23.3 \text{ mg kg}^{-1} 7\text{d}^{-1}$) and microbial biomass carbon (283 mg kg^{-1}) were also the highest under this integrated inorganic and organic treatment in conjunction with no tillage. Naresh *et al.*, 2016 showed that in 3-year experiment LFON content in 0 - 5 cm soil layer of CT system,

T₁, and T₅ treatments increased LFOC content from $5.1 \text{ mg}\cdot\text{kg}^{-1}$ in CT (T₀) to 7.9 and $9.6 \text{ mg}\cdot\text{kg}^{-1}$ without CR, and to 10.3, 11.5 and $13.1 \text{ mg}\cdot\text{kg}^{-1}$ with crop residue @ 2, 4 and 6 tha^{-1} , respectively. Compared to conventional tillage (CT), no-tillage and reduced tillage could significantly improve the SOC content in cropland. The enhanced microbial activity induces the binding of residue and soil particles into macro-aggregates, which could increase aggregates stability thus improving the concentration of SOC and increasing C sequestration (Liquin *et al.*, 2014).

Concerns and trade-offs of implementing CA

De Costa and Sangakkara, (2006) revealed that regeneration of soil fertility, through integrated nutrient management (INM), is critical to improving the agronomic productivity of smallholder farmers of Asia and elsewhere in developing countries. According to Chivenge *et al.*, (2007) 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) and reduce farmers' vulnerability to drought, and address low draught power ownership levels (Mashingaidze *et al.*, 2012). Hobbs and Govaerts, (2010) 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) 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).

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

at less cost and improve livelihoods and contribute to reduction in poverty.

- Support will need to be provided for diversification efforts, including marketing support for new produce in which farmers may not have experience of market conditions.
- Constant innovation will need to emerge on a participative basis based on experiential learning from its localized perspective.
- As is well known, the CA practice of retaining crop residue on the soil surface would encourage timely sowing of crops, reduced evaporative losses and run-off through wind and water erosion. However availability of crop residue given pressures of home fuel and livestock fodder will need to be dealt with. As such CA efforts need to become synonymous with those encouraging

growth of biomass.

Supplementary Efforts Needed

Enhancing productivity in the face of widespread problems of resource degradation is the key challenge to enhance livelihoods of the large majority of smallholder farmers.

Keeping in view the smallholder dynamics, CA practices can be made relevant to needs of such farmers thus addressing concerns of declining agricultural productivity.

Additional fallout could be the reduction in inputs deployed since these farmers largely depend on purchased inputs for their farming needs. Adoption of appropriate CA practices would enable them to improve the use efficiency of their own resources, thereby reducing dependence on purchased inputs.

Table.1 Effects of climate change on land use and livelihood systems of the poor

Land use systems	Livelihood systems of the poor *
• Reduced soil moisture	•Reduced food and nutritional security > Availability
• Problems with agricultural water management	> Access > Utilisation; and > Food systems stability
• Changes in soils due to modification of water balance	•FAO (2008)
•Ecosystems changes: genetic resources and biodiversity	•Increased risk of poverty and hunger
• Increased droughts	•Increased vulnerability
• Increased rangelands	• Inability to adapt to heat stress
• Woody encroachment	• Inability to sustain animal production as a key feature of rural livelihoods
• Desertification	•Reduced products and services from agricultural biodiversity
• Increased overstocking of heat tolerant animals	•Increased susceptibility to diseases • Reduced productivity
• Alter the suitability of land to grow crops	
• Increased salinisation	• Reduced income
Reduced biodiversity	• Reduced self-reliance
• Species adaptation and distribution	• Unstable households
• Shift out of agriculture	• Increased urban migration

* Includes the landless

Source: Yap et al., (2012)

Table.2 Mitigation options in agriculture

Practice	Relative Mitigation Potential (unit of production)	Challenges/Barriers (policy, poverty, knowledge, extension)	Opportunities (feasibility, cost effectiveness, synergy with adaptation)	Co-benefits and Contribution to Sustainable Development
Cropland management • Agronomy • Nutrient management • Tillage/residue management • Water management	Potential to sequester soil carbon by 0.55-1.14 tCO ₂ / ha/year. Potential to reduce N ₂ O emissions by 0.02-0.07 tCO ₂ -eq/ ha/ year.	This option could be costly to implement and would need considerable effort to transfer, diffuse, and deploy. Also, some measures may challenge existing traditional practices	Use of improved varieties with reduced reliance on fertilizers and other inputs provides opportunity for better economic returns. Reduced tillage will reduce the use of fossil fuel thus lower CO ₂ emissions from energy use.	Increases productivity (food security); improves soil, water, and air quality; promotes water and energy conservation; and supports biodiversity and wildlife habitat
Rice management	In continuously flooded rice fields, potential to reduce CH ₄ emission by 7%–63% (with organic amendment) and 9%–80% (with no organic amendment).	The benefit may be offset by the increase of N ₂ O emissions and the practice may be constrained by water supply.	More effective rice straw management to reduce management to reduce CH ₄ emissions (e.g. as a biofuel).	Promotes productivity (food security) and conservation of other biomes. Also enhances water quality.
Agroforestry, set-aside, land use change	Potential to sequester carbon by 0.70-3.04 t CO ₂ / ha/year; reduce CH ₄ emission by 0.02 tCO ₂ -eq/ha/ year; and reduce N ₂ O emission by 0.02-2.30 tCO ₂ -eq/ Ha/ year.	Cropland conversion reduces areas intended for food production. Also, the fate of harvested wood products would need to be accounted for.	Harvest from trees (fuel wood) could be used for bioenergy; additional returns to farmers. Set-aside is usually an option only on surplus agricultural land or on croplands of marginal productivity.	This practice promotes biodiversity and wildlife habitats; energy conservation; and, in some cases, poverty reduction. Improves the quality of soil, water and air; promotes water conservation; supports biodiversity, wildlife habitats, and conservation of other biomes.
Peatland management and restoration of organic soils	Potential to sequester carbon by 7.33-139.33 tCO ₂ /ha/year; and reduce N ₂ O emission by 0.05-0.28 tCO ₂ -eq/ha /year.	Need better knowledge of the processes involved to avoid double counting.	Avoiding row crops and tubers; avoiding deep ploughing; and maintaining a shallower table are strategies to be explored.	Improves soil quality and aesthetic/amenity value; promotes biodiversity, wildlife habitats, and energy conservation.
Restoration of degraded lands	Potential to sequester carbon by 3.45 tCO ₂ /ha per year.	Where this practice involves higher nitrogen application, the benefit of carbon sequestration may be partly offset by higher N ₂ O emissions.	-	Increases productivity (food security); improves soil and water quality and aesthetic and amenity value; and supports biodiversity, wildlife habitats, and conservation of other biomes.
Livestock management feeding practices	Improved feeding can reduce CH ₄ emissions from enteric fermentation by 1%–22% for dairy cattle; 1%–14% for beef cattle; 4%–10% for dairy buffalo, and 2%–5% for nondairy buffalo.	The effect varies depending on management of animals, i.e., whether confined animals or grazing animals.	The measure depends on soil and climatic conditions, especially when dealing with grazing animals.	Reduced pressure on natural resources (such as soils, vegetation, and water) allow a higher level of sustainability.
Manure management	Up to 90% of CH ₄ emitted can be captured and combusted, 10%–35% of CH ₄ can be reduced by composting, and 2%–50% of N ₂ O emission can be reduced through improved soil application.	Lack of incentives for the broad application of this measure would be a challenge.	Applicable to all waste management systems particularly swine production.	Fewer odours and less environmental pollution.
Bioenergy (soils only)	Potential to sequester carbon by 0.70t CO ₂ / ha / year; and reduce N ₂ O emission by 0.0 t CO ₂ -eq/ ha/year.	Competition for other land uses and impact on agro -ecosystem services such as food production, biodiversity, and soil moisture conservation.	Technical potential for biomass; technological developments in converting biomass to energy.	Promotes energy conversion.

Source: Smith *et al.* 2007

The challenge would lie in addressing constraints through sustainable interventions, many going beyond the realm of core CA efforts as outlined below:

- To the extent possible, the surface of the soil should be kept covered either by leaving crop residue on the surface or through cropping including cover crops.
- Conservation and improved crop availability of rainwater declining quality of soils
- Adopting appropriate crop rotations/sequencing including intercropping and agro-forestry practices must be an integral part of any cropping strategy
- Conventional tillage practice loses money through released carbon, decreased organic matter and more compaction. No-tillers do a better job in uniformly spreading residue which in turn is the first step towards harvesting high yields. It starts with matching the combine header width to the width of the residue spread
- Zero-tillage, if pursued in isolation will reduce cost of cultivation, but is unlikely to improve soil quality. For this reason, keeping the soil surface covered by retaining residue has to be a simultaneous effort. Since crop residues are a major source of forage in the smallholders farming, there will be a need to find ways to enhance biomass for use as soil cover. Potential of crops like *Sesbania* for being used as soil cover/mulch needs to be explored.
- CA approach based technologies need to be developed and promoted in relation to specific existing farming situations. This will call for strong adaptive research

program aimed at adapting and refining CA based practices to focus on arriving at a solution to problems of the smallholders farming.

- The benefits of no-till farming methods for sequestering carbon and increasing the content of organic matter in soil and thereby boosting yields would seem to depend on the respective climatic zones. The greatest challenge, however, is the need to overcome the tradition of routine tillage and to sensitize farmers about no-till agriculture. Particularly in subtropical Indian, farmers are reluctant to adopt the practice.

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