CROP RESIDUE MANAGEMENT: IMPACTS ON SOIL AND CROP PRODUCTIVITY

Abstract

Natural resources such as crop residues can be recycled to improve soil's physical, chemical, and biological properties. Most people consider crop residues a waste, but these can significantly improve soil conditions when appropriately used. For crop residue management, several on-field options are available to farmers, such as removal off the field, on-field burning, surface placement / retention, mulching, and incorporation into the soil. Farmers usually burn residue to avoid interference with machinery when planting their subsequent crops. Contrarily, studies indicate that incorporation and surface retention of crop residues has great potential for improving soil health. As crop residues decompose, it releases certain gluing products that promote soil aggregation, improving its physical properties, nutrient availability, and associated biological activities. Further, the presence of crop residue on/beneath the soil surface helps regulate the temperature fluctuations and enhance the moisture availability near the rooting zone of the crop, enhancing root and microbial activity and nutrient transformation. All of these results in improved soil health, thus helping to achieve sustainable agricultural production. The present chapter mainly focuses on the different on-field residue management options and their effect on soil properties and crop productivity through an array of published literature.

Keywords: Crop Productivity, Crop Residue, Residue Management, Residue Recycling, Soil Health.

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I. INTRODUCTION

Crop residues (CR) are frequently regarded as having little or no value [1, 2], but they have the potential to improve the physical, chemical, and biological properties of soil. When they are returned to the soil, they become valuable resources [3]. Intensive agriculture, with unscientific land management, depletes essential nutrients and reduces crop production potential. The soil must be physically good enough to support optimum crop growth and allow full utilization of its resources in order to produce the desired output from cultivated crops. As one of the most cost-effective ways to improve soil health, CR should be incorporated into the farming system. The total amount of CR produced in India is estimated at 350 x 106 kg year^{-1} [4]. CR management is predominant in the Indo-Gangetic plains, especially Punjab and Haryana. In Indian Punjab, it is estimated that about 7-8 million metric tonnes of rice straw is burnt every year [4] which leads to almost complete loss of soil nitrogen (N), 25% of phosphorus (P) losses, 20% of potassium (K) losses and sulfur (S) loss to about 5-60% [5]. Moreover, it deprives soils of organic matter, deteriorates structural and hydraulic properties of soil, losses huge amounts of biomass, exhausts soil flora and fauna, and contributes largely to environmental pollution creating health hazard problems and deprivation of the agricultural environment [6, 7]. Other than burning, the residue management options available for farmers are removal of straw, surface retention and mulching, and incorporation into the soil. CR, when retained on the surface or used as a mulch, serves the role of a natural blanket protecting the fertile surface soil from erosion and runoff, and reducing the impact energy of raindrops, thus preventing crust formation and surface sealing. The mulched CR further on decomposition adds SOM to the soil, thereby enhancing organic carbon, aggregation and aggregate stability of the soil.

Incorporation of CR into the soil helps to rebuild the biological activity and play a vital role in improvement and maintenance of soil physical conditions for long run. Moreover, it helps in building up SOM, improvement in soil aggregation and its stability, bulk density (BD), porosity and pore size, moisture holding capacity, hydraulic characteristics, penetration resistance [8], brings out modification in soil thermal and moisture regimes and contributes to nutrient pools of soil. It also reduces unproductive soil and water losses, soil temperature extremes and modifies microbial habitat for the proliferation of soil biota [6]. For sustaining the productive potential of cropping systems, it is essential that the management practice should aim at improving soil physical conditions via improving soil structural and hydraulic properties, that help in reducing nutrient losses, providing favourable microbial habitat and controlling soil degradation by the ways that are effective and inexpensive [9]. One of the cost effective option for improving overall condition of soil is the build-up of SOM through incorporation of CR. On farm recycling of CR is the pre-eminent management practice for restoring the declined SOM content which is identified as the nucleus for improving soil physico-chemical and biological condition and sustaining agriculture production [10].

1. **Crop residue statistics in India:** The Ministry of New and Renewable Energy (MNRE), Government of India, estimates that approximately 500 Mt of CRs are generated each year. Uttar Pradesh generates the most CRs (60 Mt), followed by Punjab (51 Mt) and Maharashtra (46 Mt). Cereals produce the most residues (352 Mt), followed by fibres (66 Mt), oilseeds (29 Mt), pulses (13 Mt), and sugarcane (12 Mt) (Figure. 1). The production of cereal CRs is the highest in Uttar Pradesh (53 Mt), followed by Punjab (44 Mt) and

West Bengal (33 Mt). The state of Maharashtra produces the most pulse residues (3 Mt), while Andhra Pradesh produces the most fibre CRs (14 Mt). Gujarat and Rajasthan produce most oilseed CRs (6 Mt).

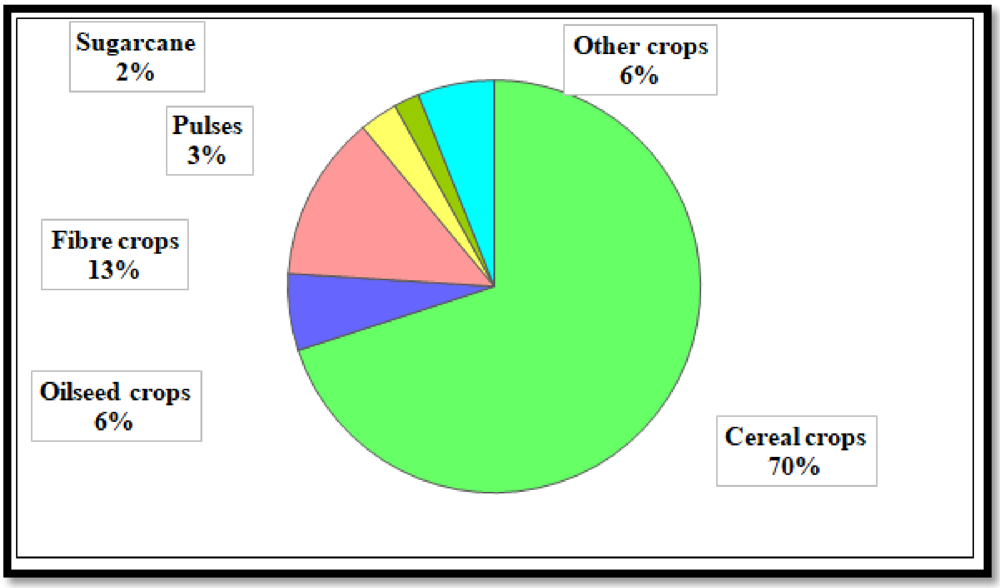

Figure 1: Contribution of various crops to total crop residue generation in India

II. CROP RESIDUE MANAGEMENT OPTIONS

For the management of crop residues, several on-field options are available to farmers as discussed below. The advantages and disadvantages of each management option must be considered.

1. **Residue burning:** As a low-cost practice, residues are traditionally removed for animal feeding. However, in recent few years, since machines are used for harvesting, it leaves loose straw on the soil surface and hence to avoid any interference during planting of the subsequent crop, farmers opt for burning the CR for rapid clearing of the field. This practice is generally prevalent in the Indo-Gangetic plains (IGP), particularly in the states of Punjab and Haryana. In scientific way, burning of the crop residue is always harmful considering the soil, environment and human health. Depletion of SOM [11] and beneficial soil microbes [12] as a result of burning is one of the major causes of declining yield in the IGP.

2. **Surface retention and mulching:** Another management option is the placement or retention of a thin layer of crop residue on the soil surface. This offers a great advantage for the protection of the surface soil layer from wind and water erosion. Further, the surface retained residue on decomposition adds significant quantities of OM and other essential nutrients as well as moderate temperature fluctuations [13]. It has been reported by "reference [14]" that this practice can increase the N content of soil by 46% and crop yield by 37%, over burning of CR. The major disadvantage of this practice is the amount of residue that is retained on the soil surface. When large amounts of CR are retained on

the soil surface, it may affect the operations of machines and may result in even machine failure too.

3. **Residue removal:** Removal of residues reduces the amount of organic binding agents required for aggregate formation and stability, which has a negative effect on aggregate stability. Furthermore, raindrop impacts close open-ended bio-channels, which affects the water holding and transmitting characteristics (e.g. infiltration, hydraulic conductivity (HC)) of the soil, thereby increasing the extent of soil loss through runoff or erosion. Additionally, residue removal results in evaporation of surface soil moisture, increases diurnal temperature fluctuations, and reduces organic matter input required to improve soil water retention.

4. **Residue incorporation:** The fourth on-field CR management option is its incorporation into the soil at the desired depth using the appropriate tillage methods [15]. This practice is reported to be very efficient in improving the overall soil health [16]. Unlike removal or burning, straw incorporation increases SOM, N, P, and K content. However, the residue incorporation in soil, particularly of cereals, results in short-term deficiency of N through its immobilization, resulting in decreased crop yields by about 40% [17]. The research findings report that it is possible to overcome the N immobilization problem by applying 15-20 kg ha^{-1} of N as a starter dose along with CR incorporation, which leads to a higher yield than burning straw [18].

III. RESIDUE MANAGEMENT EFFECTS ON SOIL HEALTH AND CROP PRODUCTIVITY

Many researchers around the world studied the effects of rice straw incorporation on soil physico chemical as well as biological properties under a wide range of soil and climatic conditions and reported positive effects on soil physical parameters such as soil porosity (SP), aggregation, BD, penetration resistance (PR), HC, soil chemical properties such as available nutrient content, and soil biochemical properties such as enzyme activities, and carbon fractions. All of this resulted in an improvement in overall soil health, which eventually leads to higher crop yields in the long run.

1. **Effect on soil bulk density (BD) and porosity (SP):** The incorporation of CR into soil reduces the BD of soil. CR incorporation in the soil increases the microbial activity and residue decomposition products favour more aggregation and thus reduce BD. Furthermore, because the residue is lighter than mineral matter, BD should decrease with dilution [19]. SP has a direct inverse relationship with soil BD, so as BD decreases, porosity tends to increase. When aggregates form and grow in size, cavities form and expand within and between the aggregates. A conduit for fluid transport is created when these cavities are connected to each other [19] (Shaver, 2010). In Punjab, India, “reference [20]” in a long-term experiment reported decrease BD in rice straw managed treatment over control. Among different treatments, treatments consisting of wheat straw + urea + rice straw incorporation resulted in a maximum reduction in BD (1.65 Mg m^{-3}) because of the incorporation of the residue of both crops.

Similarly in another study in the Philippines, “reference [21]” reported that all the plots receiving rice straw significantly decreased the soil BD. BD under control and straw burnt plot were statistically at par, but straw incorporation had resulted in lowering of soil BD over burning and control mainly because of increase in soil organic carbon (SOC) storage. While studying the long-term effect of CR incorporation on two different soil types, "reference [22]" reported lower BD with CR incorporation in both soil types. However, the magnitude of decrease was highest in Shahpur soil (coarse silty in texture and low SOM) as compared to Awagat soil (fine loam texture). Similar results were also reported for the SP. This was mainly attributed to the property of CR in improving soil structure mainly in the soil with a light texture and low SOM content. "Reference [23]" studied the long-term effect of different levels of wheat straw mulch (0, 8, and 16 Mg ha^{-1} $year^{-1}$) on a silt loam soil of Central Ohio and reported that in 0-3 cm soil depth, 16 Mg ha^{-1} $year^{-1}$ treatment lowered the BD by 58% (0.84 Mg m^{-3}) and 8 Mg ha^{-1} $year^{-1}$ treatment by 19% (1.11 Mg m^{-3}) than BD under 0 Mg ha^{-1} $year^{-1}$ (1.32 Mg m^{-3}). Similarly, SP was also affected by wheat straw mulch. The SP under 0, 8, and 16 Mg ha^{-1} $year^{-1}$ of wheat straw mulch was 0.50 m^3 m^{-3}, 0.64 m^3 m^{-3}, and 0.72 m^3 m^{-3}, respectively and it increased by about 28% and 44% under 8 and 16 Mg ha^{-1} $year^{-1}$ of wheat straw mulch over control treatment. However, "reference [24]" in Lithuania did not find any significant effect of chopped straw incorporation on soil BD in the upper 3-13 cm and lower 15-25 cm depth soil layer. They reported a BD of 1.25–1.49 Mg m^{-3} in the upper soil layer without straw and 1.29–1.47 Mg m^{-3} in the plot with straw incorporation. In a three-year study with different tillage practices and eight levels of CR management under the wheat (w)-mungbean (m)-rice (r) cropping system, "reference [10]" in Bangladesh reported that BD under the Swrm (where the residue of all three crops were incorporated) was found to be the lowest (1.38 Mg m^{-3}) followed by Smr (1.40 Mg m^{-3}) and Smw (1.40 Mg m^{-3}) having incorporation of two CRs. S_0 (Plot without incorporation of CR) showed the highest BD (1.44 g cm^{-3}). Similarly, Swrm showed the highest SP (43.2%) while the lowest was in S_0. However, "reference [25]" in Canada did not find any significant effect of CR on BD.

However, when averaged across CR, BD was higher for No-tillage than tillage by about 15% in black Chernozen and 18% in gray Luvisol. Similar results have been reported by "reference [26]" in Vertisol soil type of Australia where the effect of residue management on BD was non-significant. While studying the effect of conservation tillage on the productivity of wheat for 15 years (1992-2006) in Northern China, "reference [27]" reported that for the first six years, BD was significantly less for CT (conventional till). It was statistically uniform for CT and NTSC (no-till and residue cover) in the next five years, afterwards, NTSC resulted in the lowering of soil BD. The SP increased with the increasing mulch rate [28]. However, lower mulching rates up to 5 Mg ha^{-1} $year^{-1}$ did not show any significant difference in SP. Up to 5 Mg ha^{-1} $year^{-1}$, the mean SP was 0.3% and it increased by about 173% under 10 and 15 Mg ha^{-1} $year^{-1}$ of mulch rate. "Reference [7]" reported that CR management significantly affected the SP of soil. It was 49.4, 48.8, 51.9, and 54.6% under control, straw burning and removal, straw incorporation, and straw incorporation plus FYM treated plot, respectively. Similar results have been reported by [29] [30]. The SP was lower for low mulch rate and it increased by about 95% with 8 Mg ha^{-1} of mulch rate. In a short-term study in Western Nigeria, "reference [31]" reported decreased BD with increasing mulch rate in 0-5 cm soil layer i.e. 1.17 Mg m^{-3} under control to 0.97 Mg m^{-3} with 8 Mg ha^{-1} of mulch treatment. Similarly, "reference [32]" observed 58% lower BD under the high-mulch treatment and 19% lower under the low-mulch treatment as compared to the BD under the no-mulch treatment for the 0-3 cm depth.

2. **Effect on soil aggregation and aggregate stability:** As CR return to the soil increases, the soil is protected from the direct impact of raindrops, thus prevents aggregate disruption and sealing of surface soil [33]. In northwest India, while studying the effect of CR and manure application on soil aggregation in the rice-wheat cropping system, "reference [34]" reported that application of rice straw and FYM resulted in an increase in aggregation especially macro-aggregates, a decrease in micro-aggregates, and the effect was not significant for the application of nitrogenous fertilizers. They further reported that at 0-5, and 5-10 cm soil layer, the macro-aggregate formation was enhanced significantly with the application of rice straw and FYM. However, at 10-15 cm, the improvement in > 2 mm fraction was the least. When assessed across different nitrogen rates, an abundance of macro-aggregates was found with the incorporation of rice straw at 0-5 cm soil layer. Similarly, in the arid lands of the Loess Plateau of China, "reference [35]" reported that aggregate stability was high in 0-10 cm soil depth and decreased with an increase in soil depth. In the two years of experimentation, aggregate stability in 0-10, 10-20, and 20-30 cm soil layer were 5.0-23.2%, 10.3-32.1%, 10.6-47.9% respectively, and significantly higher for straw incorporation treatments over control plot receiving only inorganic fertilizer. In another short-term study, "reference [36]" reported that straw incorporation resulted in a reduction of 2.0-0.25 mm aggregate fraction as compared to control plots. However, no significant influence of straw incorporation on aggregates in the size range >2.0 mm or < 0.25 mm has been reported. "Reference [37]" reported that compared with no residue treated plots, soil aggregation was improved in CR treated plots and had a higher proportion of large macro-aggregates than the small macro-aggregates. While studying the effects of different mulching rates, "reference [29]" found that water-stable aggregates were higher in 16 Mg ha^{-1} $year^{-1}$ mulch rates, ranging from 38% to 67%, and lowest under plot without mulch. Similar results have been reported for mean weight diameter (MWD) which was highest for mulch rate no mulch. "Reference [25]" in Canada reported a higher value of MWD under no-tillage and residue retention and least under tillage without residue. Similarly, "reference [38, 39, 40]" showed that CR incorporation was the most effective for increasing the stability of soil aggregates particularly under the rhizosphere zone.

3. **Effect on surface sealing and soil penetration resistance (SPR):** A soil penetration resistance is the result of cohesive forces and frictional resistance between soil particles that are forced to slide over one another or ride out of their interlocking positions to allow roots to grow. Except for cracks and macropores, root elongation in soils is possible only to the extent that root pressure exceeds soil penetration resistance [41] [42]. In Bangladesh, "reference [43]" reported that SPR was significantly reduced by retention of a higher amount of CR as compared to a lower amount. SPR in 0-5 and 5-10 cm soil layer under the low amount of residue retention was 80, 152 and 69, 134 N cm^{-2} under a high amount of residue retention. However, at lower soil layers i.e. 10-15 cm, the effect was not significant. Similarly, "reference [44]" in Norway reported that straw management treatments significantly improved the modulus of rupture (a test used to characterize soil penetration). However, "reference [24]" did not find any significant influence of straw incorporation on PR. At depth of 1.5-9.0 cm, PR was highest and changed drastically from 223 to 1115 kPa in straw removed plot and from 208 to 1053 kPa in straw

incorporated plots, respectively. At depth 9.0-22.5 cm, PR changed from 1115 to 1175 kPa in straw removed plot and from 1053 to 1211 kPa in straw incorporated plots. In another study, "reference [31]" observed significantly lower PR under different rates of mulch treatments. At soil depth 0-5 cm, PR under control was 1.54 kg cm^{-2} and reduced to 1.07 kg cm^{-2} under 8 Mg ha^{-1} of mulched treatment. They also reported that for the top 40 cm soil layer, PR tends to decrease with an increase in soil depth. The mulched treatment had lower PR mainly because of higher soil moisture in the mulched treatment [45]. Conversely, "reference [23]" in central Ohio reported that mulching did not influenced the PR of soil in upper 0-5 cm soil layer.

4. **Effect on hydraulic properties of soil:** The increase SOM following CR incorporation improves the soil structural stability as discussed above. A soil with high structural stability also increases the soil water content [23]. Soil erosion can be reduced by up to 90% compared to an unprotected, intensively tilled field, depending on the amount of CRs left on the soil surface. The hydraulic properties of soil viz. IR, HC, and soil moisture have been reported to be affected significantly by CR incorporation. "Reference [46]" reported the reduced BD in 0-15 cm soil depth with incorporation of rice and wheat straw with associated increase in saturated HC because of increase in macro-porosity of soil. Incorporation of residue of both wheat and rice crop increased the IR of soil. Initial IR was maximum (7.0 mm hr^{-1}) where residue of both crops incorporated, after five hours, it varied from 2.0 mm hr^{-1} under less intensive tillage without CR to 4.0 mm hr^{-1} where residue of both crop where incorporated. In another study, "reference [22]" reported the favourable effect of residue incorporation on infiltration because of presence of greater proportion of macro and mesopores and lowered soil BD in both Awagat and Shahpur soil. While studying the effect of different tillage treatments, "reference [47]" reported that sorptivity of straw retained treatment was significantly lower than straw burnt treatment at lower potential (-40 mm). Significantly higher amount of available soil moisture was detected in straw retained direct drilled treatment as compared to straw burnt conventional till system. Similarly, "reference [48]" on a sandy loam soil also reported that total as well as final infiltration were significantly higher with zero tillage in combination with CR retention as compared to conventional tillage. While studying the effect of three types of CRs, "reference [10]" reported higher soil moisture content by 31% in the plot receiving residues of all three crops (wheat, rice and mungbean) than plot without CR incorporation.

In contrast, "reference [28]" in Spain did not find any significant difference in water content at mulching rate of 1 and 5 Mg ha^{-1} $year^{-1}$ over control. At higher mulching rates of 10 and 15 Mg ha^{-1} $year^{-1}$, there were about 18% higher soil moisture for all suction intensities. They also reported about 7.6% higher HC with mulching rate of 10 and 15 Mg ha^{-1} $year^{-1}$ as compared to control and low mulching rates and no any benefit was found beyond 10 Mg ha^{-1} $year^{-1}$ of mulch rate. "Reference [49]" in Japan studied the effect of rice straw mulch and nitrogen fertilization on soil moisture content during wheat growth and found that in the surface soil, moisture content was reduced at faster rate in the plot without rice straw mulch i.e. from 33.2% at sowing to 14.1% after 20 days of sowing. The moisture content under 4 Mg ha^{-1} of rice mulch retained highest percentage of soil moisture i.e. 21% after 20 days of sowing. They reported significantly higher amount of soil moisture even after removal of rice straw from previously mulched plot.

With increasing nitrogen fertilizer rate, soil moisture content decreased due to more crop growth and enhanced transpiration.

5. **Effect on soil organic carbon (SOC):** In the 11 years of continuous rice-wheat rotation, “reference [50]” reported that SOC content improved by 34% with the incorporation of rice straw and application of FYM. “Reference [51]” reported that sandy loam soil with low initial SOC had great potential for increasing SOC content as evident by a 29.6% increase as compared to 11.6% in silt loam soil, in straw retained treatments compared with straw burning. Likewise, In NW China, “reference [8]” reported that maize straw incorporation resulted in an increase in SOC storage. SOC storage for straw incorporation @ 4500 kg ha^{-1} was 7.7% in 2008 and it increased to 21.4% in 2010 over control. As compared to control, straw incorporation @ 4500 kg ha^{-1} showed a significant increase in SOC storage, but no significant difference was found between straw incorporation @ 9000 and 13,500 kg ha^{-1}. In another study, “reference [52]” in the USA also reported higher SOC stock where CR was retained and incorporated as compared to complete and partial residue removal. In long-term research, “reference [53]” showed that the SOC content of soils was significantly increased with the application of rice straw at the rate of 12 t ha^{-1} and wheat straw at the rate of 6 t ha^{-1}. Similarly, in the cotton wheat system, “reference [22]” reported a significant increase in SOM with straw incorporation as compared with straw removal. This effect was more pronounced in coarse silty soil as compared to fine loamy soil.

Contrarily in Nepal “reference [54]” under rice –wheat system did not find significant influence of incorporation of CR on SOC content of the soil. In Southern Spain, while working with mulched treatments, “reference [28]” also did not find any significant difference in SOM content between mulching rates of 1 Mg ha^{-1} $year^{-1}$ and control. Increasing mulching rates from 5 Mg ha^{-1} $year^{-1}$ resulted in an increase in organic matter ranging between 3.1-4.4% and the highest increase was reported for mulching rates of 10 and 15 Mg ha^{-1} $year^{-1}$. In a long-term experiment at China, “reference [55]” reported that the mean SOM for no-till with straw was 18.8 g kg^{-1} in the 0-0.05 m soil depth which was significantly greater than conventional tillage plots i.e. 14.3 g kg^{-1}. “Reference [56]” reported that the incorporation of CR increased the SOC content by about 4.8% but did not find a significant difference in SOC content between residues returned and removed treatments. Similarly, “reference [57]” reported increased SOC with residue retention along with nitrogen inputs. “Reference [58]” found that with rice straw incorporation, SOM increased from 6.4% in 2008 to 12.2% in 2010.

6. **Effect on soil available nutrients:** In a long-term study at Ludhiana, Punjab, “reference [17]” found that the incorporation of CR resulted in a higher concentration of total nitrogen (TN) as compared to treatments with residue removal or burning. Similarly, available phosphorus (AP) content was also greater in plots with residue incorporation as compared to its removal or burning. The burning of CR resulted in decreasing AP content because of its loss to the atmosphere. “Reference [59]” and “reference [60]” also reported that TN content was significantly improved with rice straw incorporation as compared to the burning of CR. In Vertisol soil type, “reference [61]” reported that TN and mineralizable N in 0-10 cm soil depth was significantly higher in treatment with no-tillage residue retention and increasing level of fertilizer N. Similarly, “reference [60]” reported 29.2% increase in N with the incorporation of CR. Similar results also have been

reported by "reference [62]". In Philippines, "reference [21]" reported that all the plots receiving rice straw treatment showed significantly highest available potassium (AK) ranging from 375 kg ha^{-1} in 50% straw incorporation to 495 kg ha^{-1} in residue burning over control (355 kg ha^{-1}). In NW China, "reference [63]" reported that different nutrient management treatments had significantly improved the soil nutrient status as compared to control. Treatment comprising of Straw + NP, and FYM showed significantly higher nutrient content over control and other treatments. Similarly, "reference [27]" in NW China reported that no-tillage in combination with residue retention showed significantly higher TN and AP by about 25.6% and 4.4% respectively.

7. **Effect on enzyme activities and soil carbon pools:** Soil enzymes are vital components of the soil and can serve as the indicator of soil quality and portray the potential soil fertility under different management interventions. The activity of enzymes in the soil is governed by the different management practices and ameliorative measures which affect the soil properties of biologically most active surface horizons. In the rice-wheat cropping system, "reference [64]" reported the highest activity of dehydrogenase (DHA) in rice straw incorporated treatment as compared to rice straw removal. "Reference [65]" in the rice-wheat system, also reported that DHA activity was 2 times higher in rice straw compost incorporated treatment as compared to no compost incorporated treatments. Similarly, significantly higher activity of DHA was observed in 0-30 cm soil depths with the incorporation of wheat residue than its burning "reference [66]". "Reference [67]" reported the higher microbial biomass and enzyme activities following rice straw incorporation as it acts as a source of food and energy for microbes. In the maize-wheat cropping system, "reference [68]" reported 14.6% higher activity of fluorescein diacetate (FDA) enzyme in 0-5 cm soil depth under 75% CR retention as compared to without retention. In the rice-wheat-mungbean cropping system, "reference [69]" reported an 18% increase in FDA activity after 9 years of CR and vermicompost incorporation than no straw and vermicompost incorporation.

"Reference [70]" under the wheat-fallow cropping system reported that the activity of the acid phosphate (acid P) enzyme decreased by straw burning as compared to straw incorporation. In another experiment, "reference [71]" reported that the incorporation of maize residue at the rate of 7.5 t ha^{-1} increased the activity of alkaline phosphate (alk P) by about 80% as compared to no residue. Similarly, "reference [72]" reported a significant improvement in alk P activity after the incorporation of wheat straw. Soil labile carbon pools are considered the soil quality indicators and are influenced by CR management practices [73, 74]. While working in the rice-wheat cropping system, "reference [27]" reported that water-soluble carbon (WSC) increased by about 71-109% in rice straw incorporated treatments as compared to without rice straw incorporation. Similarly, "reference [75]" in China reported that the incorporation of 50% and 100% CR has significantly increased WSC content as compared to straw removal. It increased by 34 and 71% under 50 and 100% CR incorporation [75]. In another study, "reference [69]" in the rice-wheat and rice-wheat-mung bean cropping system reported higher basal soil respiration (BSR) in FYM and CR amended plot.

"Reference [58]" also reported higher cumulative CO_2 under incorporation of CR at the rate of 10 t ha^{-1} as compared to control. Similarly, "reference [76]" in an incubation study observed that BSR was significantly higher in rice straw incorporated treatments.

Rice straw incorporation increased the BSR by 2.7-2.8% over no straw incorporation. “Reference [75]” in China reported that the incorporation of 50% and 100% rice straw increased the microbial biomass carbon (MBC) as compared to control. The magnitude of increase was higher after ten years of rice straw incorporation than after two years. However total organic carbon (TOC) was not affected significantly by rice straw incorporation as compared to control after two years of experimentation, but after ten years significant increment was reported. However, “reference [77]” reported the minimal effect of CR retention on TOC content, but MBC was affected significantly in CR retained treatments.

8. **Effect on crop productivity:** In Eastern India, “reference [46]” observed the increased productivity of rice-wheat system following rice and wheat straw application as compared to its removal. This was mainly attributed to improvement in SOC levels, reduces evaporative loss of water, and improved water infiltration, which improved the soil’s physical conditions and reduced the nutrient losses. Similarly, “reference [58]” showed a significant increment in grain yield with rice straw incorporation and N fertilization. In another study, “reference [78]” observed that the grain yield of corn and soybean could reduce by about 0.10 Mg ha^{-1} with the removal of each Mg ha^{-1} of residue. “Reference [56]” in Pakistan reported that the incorporation of CR increased the grain yield of maize by 23.7% as compared to residue removal treatments. Similar results have been reported by “reference [79]” about a 37% increase in grain yield of cereals with CR incorporation as compared to without incorporation. “Reference [80]” reported increased maize yield with an increasing amount of CR. The highest yield (4900 kg ha^{-1}) was found under a plot that received 150% of CRs from the previous crop as compared to the control. While a number of studies reported the higher grain yield with residue management, there are few studies that reported the decrease or variable effect of CR on crop productivity. “Reference [57]” reported that lentil grain yields during 1995- 96 were 0.82 and 1.17 t ha^{-1}, 0.28 and 0.35 t ha^{-1} in 1996-97, and 1.63 and 1.24 t ha^{-1} in 1997-98 under residue removal and residue retained treatments. When averaged over all years, no significant effect of residue retention and residue removal on the grain yield of lentils was reported. In sandy clay loam soils of the Philippines, “reference [21]” did not find any significant effect of residue treatments on grain yield in the first and second cropping cycle, however in the third and fourth cropping cycle, 100% straw treated plots showed significantly higher grain yield as compared to 50% straw incorporation and control. In the last cropping cycle, burning of residue recorded the highest grain yield of about 18.5% over control followed by 100% straw + green manure (16.8%) and 100% straw (15.4%). Similarly, “reference [81]” in a long-term experiment, reported that some years showed higher grain yield while some not. However, the overall effect was found to be non-significant.

Such variable reports have also been presented by “reference [44]” who reported that in the first year of experimentation, the different straw management treatments did not show any significant effect on grain yield. In the second year, the grain yield was significantly improved with the incorporation of normal and double amounts of straw. However, in the fourth year of experimentation, straw-managed treatments showed a significant negative impact on grain yield. On average, the incorporation of normal and double amounts of straw increased the mean grain yields by 0.29 Mg ha^{-1} as compared to other treatments. “Reference [82]” in Kenya did not find any significant effect of CR management in combination with tillage practices on the grain yield of maize and soybean. In Punjab, India, "reference [17]" found that residue burning resulted in the highest yield of rice and wheat as compared to incorporation or residue removal. The reduction in yield with residue incorporation was mainly due to the immobilization of N and P. "Reference [17]" further reported that residue incorporation together with the application of N @ 60, 120, and 180 kg ha^{-1} resulted in a depression of wheat yield by 0.54, 0.27, and 0.08 Mg ha^{-1}, respectively. However, the positive effects of residue incorporation were reported after 13 years when residue management practices were discontinued. A simplified mechanism of how crop residue improves soil health and crop productivity is depicted in Figure 2.

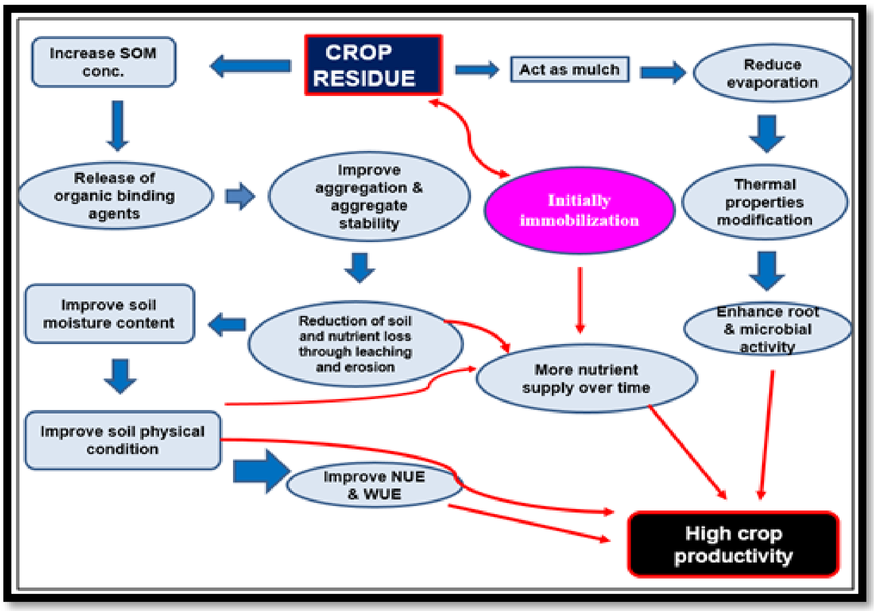

Figure 2: Simplified Mechanism of How Crop Residue Improves Soil Health and Crop Productivity

IV. CONSTRAINTS OF USING CROP RESIDUES IN THE FIELDS

Using CRs in the fields present a number of challenges. These include difficulties in sowing and applying fertiliser and pesticides, as well as pest infestation issues [83]. The zero-till seed-cum-fertilizer drill system has been greatly improved to provide farmers with trouble-free technology. The other bottleneck is weed control, particularly in the rice-wheat system. Excessive use of chemical herbicides may be unsuitable for a healthy environment. Because of higher residue levels and fewer options for nutrient application, particularly through manure, nutrient management may become more complex. It is possible for fertilisers, particularly N, applied entirely at the time of seeding to lose their efficacy and cause environmental pollution. The adoption of residues incorporation systems is further limited by additional management skills, an expectation of lower crop yields and/or economic returns, negative attitudes, and institutional obstacles. Furthermore, farmers prefer clean, well-maintained fields over shabby fields that have been tilled.

V. CONCLUSION

The management of crop residue is a massive obstacle for farmers. Burning of crop residue clears the land quickly to perform timely planting of the subsequent crop. However, this practice is harmful considering the soil, environment, and human health. Besides burning, farmers have several residue management options: removal off the field, surface placement/retention, mulching, and incorporation into the soil. Researchers found the incorporation and surface retention of straw very effective. These options help maintain agronomic productivity by enhancing soil organic matter, quantity, and availability of essential nutrients and soil moisture, promoting biotic activity and, thus, overall soil health. In addition, in most of the cropping systems in India, declining soil organic carbon is a significant threat to yields. As a result, incorporation or surface retention of crop residue can be a better option to increase soil organic carbon level. As long as crop residues are managed scientifically, soil health can be improved, and crop productivity can be sustained.

REFERENCES

[1] McKinney R E. In: Environmental Pollution Control Microbiology. Marcel Dekker, New York, 2004, 447.
[2] Lal R, Kimble J M. Conservation tillage: Prospects for the future. In: Proc. Intl. Conf. on Managing Natural Resources for Sustainable Agricultural Production in the 21st Century (Invited Papers), 2002; 14(18):116-125.
[3] Wilhelm W W, Johnson J M F, Karlen D, Lightle D (2007) Corn stover to sustain soil organic carbon further constrains biomass supply. Agron J. 99:1665-1667
[4] Punjab Remote Sensing Centre (2015) Monitoring residue burning through satellite remotes sensing. Report submitted to Punjab pollution control board, Patiala.
[5] Dobermann BA and Fairhurst T H (2002) Rice straw management. Better Crops Int. 16:7-11.
[6] Blanco-Canqui H and Lal R (2009) Corn stover removal for expanded uses reduces soil fertility and structural stability. Soil Sci Soc Am J. 73:418-26.
[7] Mandal K G, Misra A K, Hati K M, Bandyopadhyay K K, Ghosh P K and Mohanty M (2004) Rice residue management options and effects on soil properties and crop productivity. Food Agric Environ. 2:224-31.
[8] Zhang P, Wei T, Jia Z, Han Q and Ren X (2014) Effects of straw incorporation on soil organic matter and soil water-stable aggregates content in semiarid regions of Northwest China. PLOS ONE 9:928-39.
[9] Lal R, DeYleeschauwer D and Nganje R M (1980) Changes in properties of newly cleared Alfisol as affected by mulching. Soil Sci Soc Am J. 44:827-33.
[10] Salahin, N, Alam K, Mondol A, Islam M S, Rashid M H and Hoque M A (2017) Effect of tillage and residue retention on soil properties and crop yields in wheat-mungbean1rice crop rotation under Subtropical Humid Climate. Open J Soil Sci. 7(01), 1.
[11] Staniforth A R Straw for fuel, feed and fertilizer? Farming Press, Ipswich, England, 1982.
[12] Raison R J (1979) Modification of the soil environment by vegetation fires, with particular reference to nitrogen transformation: a review. Plant Soil 51:73-108
[13] Rasmussen P E, Collins H P (1991) Long-term impacts of tillage, fertilizer, and crop residues on soil organic matter in temperate semi-arid regions. Adv Agron. 45:93-134
[14] Bacon P E (2013) Effect of nitrogen fertilization and rice stubble management techniques on soil moisture content, soil nitrogen status, and nitrogen uptake by wheat. Field Crop Res. 17:75-90
[15] Ball B C, Robertson E A G (1990) Straw incorporation and tillage methods: Straw decomposition, denitrification and growth and yield of wheat. J Agric Eng Res. 46:223-243

[16] Christian D G, Bacon E T G (1991) The effect of straw disposal and depth of cultivation on the growth, nutrient uptake and yield of winter wheat on a clay and a silt soil. Soil Use Manage. 7:217-222.
[17] Sidhu B S and Beri V (1989) Effect of crop residue management on yields of different crops and soil properties. Biol Wastes 27:15-27.
[18] RWC-CIMMYT. Addressing Resource Conservation Issues in Rice-Wheat Systems of South Asia: A Resource Book. Rice-Wheat Consortium for the Indo-Gangetic Plains-International Maize and Wheat Improvement Centre, New Delhi, India, 2003.
[19] Shaver T. Crop Residue and Soil Physical Properties. Proceedings of the 22nd Annual Central Plains Irrigation Conference, Kearney, NE, 2010.
[20] Singh G, Jalota S K and Singh Y (2007) Manuring and residue management effects on physical properties of a soil under the rice-wheat system in Punjab, India. Soil Till Res. 94:229-38.
[21] Surekha K, Kumari A P, Reddy N M, Satyanarayana K and Cruz P C (2003) Crop residue management to sustain soil fertility and irrigated rice yields. Nutr Cycl Agroecosyst. 67:145-54.
[22] Hassan M M, Rafique E and Rashid A (2013) Physical and hydraulic properties of Aridisols as affected by nutrient and crop-residue management in a cotton-wheat system. Acta Scientiarum Agron. 35:127-37.
[23] Blanco-Canqui H and Lal R (2007) Impacts of long-term wheat straw management on soil hydraulic properties under no-tillage. Soil Sci Soc Am J. 71:1166-73.
[24] Boguzas V, Kairyte A and Jodaugiene D (2010) Soil physical properties and earthworms as affected by soil tillage systems, straw and green manure treatment. Zemdirbyste Agric. 97:3-14.
[25] Singh B and Malhi S S (2006) Response of soil physical properties to tillage and residue management on two soils in a cool temperate environment. Soil Till Res. 85:143-53.
[26] Dalal R C, Allen D E, Wang W J, Reeves S and Gibson I (2011) Organic carbon and total nitrogen stocks in a Vertisol following 40 years of no-tillage, crop residue retention and nitrogen fertilisation. Soil Till Res. 112:133-39
[27] Li H, Gao H, Wu H, Li W, Wang X and He J (2007) Effects of 15 years of conservation tillage on soil structure and productivity of wheat cultivation in northern China. Aust J Soil Res. 45:344-50.
[28] Jordan A, Zavala L M, Gil J (2010) Effects of mulching on soil physical properties and runoff under semi-arid conditions in southern Spain. Catena 81:77-85.
[29] Mulumba L N and Lal R (2008) Mulching effects on selected soil physical properties. Soil Till Res. 98:106-11.
[30] Oliveira M T and Merwin I A (2001) Soil physical conditions in a New York orchard after eight years under different groundcover management systems. 234, Issue 2, pp 233-37.
[31] Lal R (2000) Mulching effects on soil physical quality of an Alfisol in Western Nigeria. Land Degrad Develop. 11:383-92.
[32] Marahatta S, Sah S K, MacDonald A, Timilnis J and Devkota K P (2014) Influence of conservation agriculture practices on physical and chemical properties of soil. Int J Adv Res. 2:43-52
[33] Blanco-Canqui H, Lal R, Post W M, Izaurralde R C, Owens L B (2006a) Soil structural parameters and organic carbon in no-till corn with variable stover retention rates. Soil Sci. 171:468-482.
[34] Benbi D K and Senapati N (2010) Soil aggregation and carbon and nitrogen stabilization in relation to residue and manure application in rice-wheat systems in northwest India. Nutr Cycl Agroecosyst. 87:233-47.
[35] Wang X, Jiaa Z, Liang L, Yang B, Dingac R, Nie J and Wang J (2015) Maize straw effects on soil aggregation and other properties in arid land. Soil Till Res. 153:131-36.
[36] Soona Y K and Lupwayi N Z (2012) Straw management in a cold semiarid region: Impact on soil quality and crop productivity. Field Crops Res. 139:39-46.
[37] Singh G, Bhattacharyya R, Das T K, Sharma A R, Ghosh A, Das S and Jha P (2018) Crop rotation and residue management effects on soil enzyme activities, glomalin and aggregate stability under zero tillage in the Indo-Gangetic Plains. Soil Till Res. 184:291-300.

[38] Wei C F, Gao M, Shao J G, Xie D T and Pan G X (2006) Soil aggregate and its response to land management practices. China Particuology 4:211-19.
[39] Sonnleitner R, Lorbeer E and Schinner F (2003) Effects of straw, vegetable oil and whey on physical and microbiological properties of a chernozem. App Soil Ecol. 22:195-204
[40] Karami A, Homaee M, Afzalinia S, Ruhipour H and Basirat S (2012) Organic resource management impacts on soil aggregate stability and other soil physicochemical properties. Agric Ecosyst Environ. 148:22-28.
[41] Ruan H X, Ahuja L R, Green T R, Benjamin J G (2001) Residue cover and surface-sealing effects on infiltration: numerical simulations for field applications. Soil Sci Soc Am J. 65:853-861.
[42] Passioura, J B (2002) Soil conditions and plant growth. Plant, Cell & Environment 25(2), 311-318.
[43] Salahin N, Jahiruddin M, Islam M R, Bell R W, Haque M E and Alam M K (2014) Effects of minimum tillage practices and crop residue retention on soil properties and crop yields under a rice-based cropping system. In: Proceedings of the Conference on Conservation Agriculture for Smallholders in Asia and Africa. December 2014, Mymensingh, Bangladesh. (Eds. Vance W H, Bell R W, Haque M E). pp 133-34.
[44] Borresen T (1999) The effect of straw management and reduced tillage on soil properties and crop yields of spring-sown cereals on two loam soils in Norway. Soil Till Res. 51:91- 102.
[45] Lee Y H, Ahn B K and Lee J H (2010) Effects of rice straw application and green manuring on selected soil physical properties and microbial biomass carbon in no-till paddy field. Korean J Soil Sci Fert. 43:105-12.
[46] Sarkar R and Kar S (2011) Temporal changes in fertility and physical properties of soil under contrasting tillage-crop residue management for sustainable rice-wheat system on sandy loam Soil. J Crop Improv. 25:262-90
[47] Chan K Y and D P Heenan (1993) Surface hydraulic properties of a red earth under continuous cropping with different management practices. Aust J Soil Res. 31:13-24.
[48] Naresh R K (2013) Rice residues: from waste to wealth through environment friendly and innovative management solutions, its effects on soil properties and crop productivity. Int J Life Sci Bt Pharm Res. 2:133-41
[49] Rahman M A, Chikushi, Saifizzaman M and Lauren J G (2005) Rice straw mulching and nitrogen response of no-till wheat following rice in Bangladesh. Field Crops Res. 91:71-81
[50] Benbi D K, Toor A and Kumar S (2012) Management of organic amendments in rice-wheat cropping system determines the pool where carbon is sequestered. Plant Soil 360:145-62.
[51] Singh Y, Humphreys E, Kukal S S, Singh B, Kaur A, Thaman S, Prashar A, Yadav S, Timsina J, Dhillon S S, Kaur N, Smith D J and Gajri P A (2009) Crop performance in permanent raised bed rice-wheat cropping system in Punjab, India. Field Crops Res. 110:1-20.
[52] Villamil M B, Little J and Nafziger E D (2015) Corn residue, tillage, and nitrogen rate effects on soil properties. Soil Till Res. 151:61-66.
[53] Bhat A K, Beri V and Sidhu B S (1991) Effect of long-term recycling of crop residues on soil productivity. J Indian Soc Soil Sci. 39:380-82
[54] Ghimire R, Lamichhane S, Acharya B S, Bista P and Sainju U M (2017) Tillage, crop residue, and nutrient management effects on soil organic carbon in rice-based cropping systems. J Integr Agric. 16:1-15.
[55] He J, Kuhn N J, Zhang X M, Zhang X R and Li H W (2009) Effects of 10 years of conservation tillage on soil properties and productivity in the farming-pastoral ecotone of Inner Mongolia, China. Soil Use Manage. 25:201-09.
[56] Shafi M, Bakht J, Jan M T and Shah Z (2007) Soil C and N dynamics and maize (Zea may L.) yield as affected by cropping systems and residue management in North-western Pakistan. Soil Till Res. 94:520-29.
[57] Shaha Z, Shah S H, Peoplesc M B, Schwenked G D and Herridge D F (2003) Crop residue and fertiliser N effects on nitrogen fixation and yields of legume-cereal rotations and soil organic fertility. Field Crops Res. 83:1-11

[58] Yuana L, Zhang Z, Cao X, Zhu S, Zhang X and Wu L (2014) Responses of rice production, milled rice quality and soil properties to various nitrogen inputs and rice straw incorporation under continuous plastic film mulching cultivation. Field Crops Res. 155:164-71
[59] Gotoh S, Koga H and Ono S (1984) Effect of long-term application of organic residues on the distribution of organic matter and nitrogen in some rice soil profiles. Soil Sci Plant Nutr. 30:273-85.
[60] Cassman K G, Datta S K, Olk D C, Alcantara J, Samson M, Descalsota J, and Dizon M (1995) Yield decline and the nitrogen economy of long term experiments on continuous irrigated rice systems in the tropics. Adv Soil Sci. 25:181-18
[61] Dalal R C (1989) Long-term effects of no-tillage, crop residue, and nitrogen application on properties of a Vertisol. Soil Sci Soc Am J. 53:1511-15.
[62] Kushwaha C P, Tripathi S K, and Singh K P (2000) Variations in soil microbial biomass and N availability due to residue and tillage management in a dryland rice agro1ecosystem. Soil Till Res. 56:153-66.
[63] Liu E, Yan C, Mei X, He W, Bing S H, Ding L, Liu Q, Liu S and Fan T (2010) Long-term effect of chemical fertilizer, straw, and manure on soil chemical and biological properties in northwest China. Geoderma 158:173-80.
[64] Basak N, Datta A, Mitran T, Mandal P and Mani P K (2016) Impact of organic and mineral inputs onto soil biological and metabolic activities under a long-term rice-wheat cropping system in sub-tropical Indian Inceptisols. J Environ Biol. 37:83-89.
[65] Goyal S, Singh D, Suneja S and Kapoor K K (2009) Effect of rice straw compost on soil microbiological properties and yield of rice. Indian J Agric Res. 43:263-68.
[66] Celik I, Barut Z B, ortas I, Gok M, Demirbas A, Tulun Y and Akpinar C (2011) Impacts of different tillage practices on some soil microbiological properties and crop yield under semi-arid Mediterranean conditions. Int J Plant Prod. 5:237-54.
[67] Chandra R (2011) Effect of summer crops and their residue managements on yield of succeeding wheat and soil properties J Indian Soc Soil Sci. 59:37-42.
[68] Kumawat C, Sharma V K, Meena M C, Kumar S, Barman M, Chobhe K A and Yadav R K (2017) Fluorescein diacetate activity as affected by residue retention and P fertilization in maize under maize-wheat cropping system. Int J Curr Microbiol App Sci. 6:2571-77.
[69] Singh G, Kumar D and Sharma P (2015) Effect of Organics biofertilizers in crop residue application on soil microbial activity in rice-wheat and rice-wheat mungbean cropping system in the Indo-Gangetic plains. Cogent Geosci. 1:1085296
[70] Dick R P, Rasmussen P E and Karle (1988) Influence of long-term residue management on soil enzyme activities in relation to soil chemical properties of a wheat-fallow system. Biol Fert Soils. 6:159-64.
[71] Zhang J, Bo G, Zhang Z, Kong F, Wang Y and Shen G (2016) Effect of straw incorporation on soil nutrients enzymes and aggregate stability in tobacco fields of China. Sustainability 8:7-10.
[72] Wei T, Zhang P, Wang K, Ding r, Yang B, Nia J, Jia Z and Han Q (2015) Effect of wheat straw incorporation on the availability of soil nutrients and enzyme activities in semi-arid areas. PLOS ONE 10:e0120994.
[73] Blair G J, Lefroy R D B and Lisle L (1995) Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. Aust J Agric Res. 46:1459-66.
[74] Plaza-Bonilla D, Alvaro-Fuentes J and Cantero-Martinez C (2014) Identifying soil organic carbon fractions sensitive to agricultural management practices. Soil Till Res. 139: 19-22.
[75] Xu M, Lou Y, Sun X, Wang, Baniyamuddin M and Zhao K (2011) Soil organic carbon active fractions as early indicators for total carbon change under straw incorporation. Biol Fertil Soils 47:745-52.
[76] Ibrahim m, Cao C G, Zhan M, Li C F and Iqbal J (2015) Changes of CO2 emission and labile organic carbon as influenced by rice straw and different water regimes. Int J Environ Sci Technol. 12:263-74

[77] Mendham D S, Sankaran K V, O'Connella A M and Grove T S (2002) Eucalyptus Globulus harvest residue management effects on soil carbon and microbial biomass at 1 and 5 years after plantation establishment. Soil Biol Biochem. 34:903-12.
[78] Wilhelm W W, Doran J W and Power J F (1986) Corn and soybean yield response to crop residue management under no-tillage production systems. Agron J. 78:184-89.
[79] Kouyaté Z, Franzluebbers K, Anthony S R, Lloyd J and Hossner R (2000) Tillage, crop residue, legume rotation, and green manure effects on sorghum and millet yields in the semiarid tropics of Mali. Plant Soil 225:141-51
[80] Power J F, Koerner P T, Doran J W and Wilhelm W W (1998) Residual Effects of Crop Residues on Grain Production and Selected Soil Properties. Soil Sci Soc Am J. 62:1393-97
[81] Uhlen G (1991) Long-term effects of fertilizers, manure, straw and crop rotation on total-N and total-C in soil. Acta Agric Scand. 41:119-27.
[82] Paul B K, Vanlauwe B, Ayukea F, Gassner A, Hoogmoeda M, Hurissoa T T, Koala S, Lelei D, Ndabamenyea T, Sixe J and Pulleman M M (2013) Medium-term impact of tillage and residue management on soil aggregate stability, soil carbon and crop productivity. Agric Ecosyst Environ. 164:14-22
[83] IARI (2012) Crop residues management with conservation agriculture: Potential, constraints and policy needs. Indian Agricultural Research Institute, New Delhi, vii+32 p.