



## Recycling of Crop Residues for Sustainable Soil Health Management: A Review

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### Authors' contributions

*This work was carried out in collaboration among all authors. Author SKD and GKY designed the review and wrote the first draft of manuscript. Author KY, CK and MKM manage the literature searches. All authors read approved the final manuscript*

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### ABSTRACT

Burning of crop residues have become a challenging issue for scientist's community as well as policy makers worldwide as it directly affects environment, soil health and the productivity of crops. Microbial mediated recycling of crop residues into an amorphous dark brown to black colloidal humus like substance under conditions of optimum temperature, moisture and aeration is need of the hour. Crop residue recycling increases sequestration of organic carbon in soil which ultimately leads to improve soil physical, chemical and biological health. Organic carbon acts as a reservoir for nutrients, needed in crop production. Crop residue management recycling is a cost-effective option for minimizing agriculture's input with maximizing output. Besides supplying nutrients to the current crop, their residual effects on succeeding crops in the system are also important. This review emphasizes on crop residue recycling by different techniques. This review paper maybe helpful to the policy makers and researchers.

*Keywords: Crop residues; composting; nutrients; organic carbon and management.*

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## 1. INTRODUCTION

In the last century, the world's population has expanded fourfold. In order to feed the rising population, this population boom continues to put strain on food supply and land. Over time, increased food production has taken a toll on the health of agricultural soils. [1,2,3] as well as their quality [4]. Because soil is one of the most valuable natural resources on the planet, it is mankind's moral responsibility to keep it healthy. However, the massive amount of food, fuel, and feed production is wreaking havoc on the ecosystem. Excessive use of chemical fertilizers, pesticides and modern cultivation practices deteriorate the soil fertility and productivity. Use of organic wastes as soil amendment may hold a good promise for improving the soil health, crop productivity and reduce the waste disposal problem. Paddy straw is one of the waste organic product whose huge quantity needs some valuable disposal solution [5].

Agricultural output has always increased due to the usage of high-yield varieties that were input-intensive and required a lot of chemical fertilisers and pesticides to maintain soil fertility and plant nutrition [6,7]. Indiscriminate use of chemical inputs into the agricultural systems has raised several problems concerned with the groundwater quality, soil agroecology and plant health [8]. This has led to serious deleterious polluting impact on soil fertility, crop production, irrigation water, nutritional produce quality, and human health [9]. Soils are continuously becoming low in organic carbon content and losing beneficial microbial communities. Agricultural wastes are waste items resulting from various agricultural operations. Harvest waste, manure, and other farm wastes, as well as hazardous wastes such as herbicides and insecticides, are all examples of agricultural waste and processing wastes like packaging material [10]. Agricultural residues are the biomass left in the field after harvesting of the economic components i.e., grain. Harvest trash, also known as crop residue, can include both field residues that remain in an agricultural field or orchard after crop harvest and process residues that remain after the crop is processed into a useable resource. Stalks and stubble (stems), leaves, and seed pods are some common examples for field residues. Sugarcane bagasse and molasses are some good examples for process residues [11]. Mustard stovers and cotton stalks are some of the best examples, left in the field after harvest.

Carbon accounts for roughly 40% of total dry biomass, residues are a good source of plant nutrients as well as the primary source of organic matter added to the soil. Carbohydrate (e.g., cellulose), proteins, lipids, and lignin are the primary components of organic matter. Their ability to ingest organic matter is reliant on their ability to manufacture the enzymes required for the breakdown of the organic matter [12]. Some amount of nitrogen and phosphorus and maximum amount of potassium and sulphur remain in vegetative parts of rice and wheat. Crop residues are the primary source of organic matter in soil. In a given climatic condition and soil type, the rate of addition of carbon inputs is an important factor for determining the amount of organic matter that can be maintained in the soil [13,14].

In India, about 700 MT of crop residues are generated annually. Because of the necessity to boost productivity in order to feed an ever-increasing population, agricultural residue creation will likewise rise in the future. Crop wastes such as cereal straws, stovers, woody stalks, and sugarcane leaves/tops are produced in large amounts every year. Milling of farm produce results in a considerable volume of residue. While some crop residues are used as animal feed, thatching for rural dwellings, residential cooking fuel, and industrial fuel, the majority of crop residues are left in the fields. It is a big issue to dispose of such a large number of crop wastes. Crop residues are burnt *In Situ* to clear the field rapidly and inexpensively and allow tillage practices to proceed sowing of upcoming crop unimpeded by residual crop material. Agricultural residues burning may emit significant quantity of air pollutants like CO<sub>2</sub>, N<sub>2</sub>O, CH<sub>4</sub>, emission of air pollutants such as CO, NH<sub>3</sub>, NO<sub>x</sub>, SO<sub>2</sub>, (Nonmethane Hydrocarbon) 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 savanna/forest fire due to different chemical composition of the crop residues and burning conditions [15,16]. Crop residues left in lagoons release methane gas and add to global warming under anaerobic decomposition.

Retaining crop residue on the soil surface is considered by many to maintain physical, chemical and biological properties in agricultural soils [17,18]. A permanent or semi-permanent organic soil cover is recommended in agricultural systems that use zero or reduced tillage, such as

conservation agriculture [19]. Some general types of conservation tillage that retain crop residue, leaves and roots on or near the surface include chiseling, stubble mulching, and no-till (NT) [20]. When using no-till systems, it is particularly essential to leave residue on the surface rather than remove it as the combination of no-till with residue removal or burning may have an even greater negative effect on soil quality in the long-term than conventional tillage practices due to excessive soil compaction and reduced water infiltration [21,22]. Feeding crop residues to edible to livestock is a very common practice in developing countries where the bulk of milk and meat is produced by mixed crop-livestock smallholdings [23,24].

Crop residue returns organic matter to the soil where it is retained through a combination of physical, chemical, and biological activities that interact and affect soil quality, including nutrient cycling. After harvest, leave more crop residue. Furthermore, if higher yields allow for adequate crop residue cover, a larger amount of residue will be accessible for animal feed or other uses [25].

Organic waste is generated in large quantities by municipalities, companies, and agriculture farms. These wastes, in addition to providing a major threat to the environment, human health, and soil toxicity, pose a serious threat to the environment, human health, and beneficial microflora [26]. Raw organic wastes should not be applied directly to land because of their higher C:N ratio, unknown composition, and potential for infections, poisonous chemicals, weed seeds, heavy metals, and foul aromas [27] have reported organic chemicals entering soil from plant litter altered the fungus community composition. Composting is the biological conversion of organic wastes into an amorphous dark brown to black colloidal humus-like substance under ideal temperature, moisture, and aeration conditions [28]. It is an economically attractive technique of waste disposal and recovery of valuable plant nutrients [29]. [30] suggested that using bio converted organic waste could help to alleviate some of the challenges related with organic waste for agricultural use. Composts increase soil biophysical characteristics, soil organic matter, and crop yields by providing plant nutrients [31].

## 2. RECYCLING OF CROP RESIDUES

One of the most popular and beneficial technologies for managing agricultural wastes is

recycling. Crop residues are a possible source of plant nutrients and have a number of advantages, including better soil health and fertility, which leads to greater agricultural productivity and biodiversity in the soil [5]. The decomposition and stabilization of readily biodegradable organic matter is mediated by microbiology in the recycling of manure and other organic wastes. Part of the organic C is released as CO<sub>2</sub>, part is incorporated into microbial cells, and the remainder is humified during the process. Aerobic bacteria employ organic matter as a substrate in the recycling process. Microorganisms decompose the substrate by breaking it down from complex to intermediate products and then to simpler compounds [32]. The C/N ratio is an excellent indicator of organic substance maturation since it has a considerable impact on microbiological growth. The N and C concentration of the substrate affects the activity of heterotrophic bacteria engaged in the breakdown process. Aerobic decomposers need carbon as a source of energy, while protein synthesis requires nitrogen. The majority of the carbon (about two-thirds) is utilised by microbes as an energy source during oxidation reactions that emit carbon dioxide (CO<sub>2</sub>), while the remaining portion is used to create protoplasm of the cells together with N, P, K, and other micronutrients. As a key nutrient, nitrogen in the form of ammonium ions is necessary. Ammonia is created via aminization of proteins, urea hydrolysis, and purines and pyrimidines, among other things. Excess carbon inhibits microbiological activity, but excess nitrogen promotes fast breakdown. Because organic C is converted into inorganic C as composting advances, the C/N ratio narrows. Microbial breakdown takes longer for materials with a greater C:N ratio. It's worth noting that the C:N ratio of compost shouldn't be too high, since this can cause the immobilization of accessible nitrogen in the soil, resulting in N deficit in plants [33,34].

The ideal conditions for microorganisms to degrade and transform lignocellulolytic crop residues have been reported to have a C:N ratio of 30 to 35 and a moisture level of 55 to 65 percent [35]. Many aerobic and anaerobic microbes, including bacterial and fungal species, have been found to have cellulosic activity. *Chaetomium*, *fusarium*, *Myrothecium*, *Trichoderma*, *Penicillium*, *Aspergillus*, and *Trichonympha*, *Clostridium*, *Actinomycetes*, *Bacteroides succinogenes*, and *Butyrivibrio fibrisolvans* are some of the fungal

and bacterial species involved for decomposition [36]. [37] reported that in composting of diverse crop residues with poultry droppings and rock phosphate, a microbial consortium consisting of *Aspergillus nidulans*, *Trichoderma viride*, *Aspergillus awamori*, and *Phanerochaete chrysosporium* was utilized, which produced enriched phosphor compost in two months. The mesophilic phase of composting is governed by mesophilic microorganisms such as bacteria from the *Pseudomonadaceae*, *Enterobacteriaceae*, *Streptomyetaceae* and *Erythrobacteraceae* families, which grow in the 15 to 35°C temperature range and use soluble compounds like sugar, amino acids, and lipids to generate exothermic reactions that raise the composting temperature to 65 to 85°C [38]. At this point, hydrolytic enzymes capable of digesting lignin, cellulose, hemicelluloses, and proteins are made [39]. *Aspergillus nidulans*, *Scytalidium thermophilum*, and *Humicola spp.*, thermophilic fungal consortia were found to be particularly effective in decomposition of soybean stover and rice straw [40]. Some psychrotrophic microbial consortium, consisting of *Eupenicillium crustaceum*, *Paceliomyces spp.*, *Bacillus atropheus*, and *Bacillus spp.*, accelerated composting at low temperature for biodegradation of rice straw [41].

### 3. EFFECT OF CROP RESIDUES ON SOIL PROPERTIES

Crop residue returns organic carbon to the soil through the interaction of physical, chemical, and biological processes that impact soil characteristics. The effects of residue addition on soil physical, chemical, and biological properties are discussed below.

#### 3.1 Soil Physical Properties

Crop residues recycling can improve soil structure through a number of methods, including (i) increasing soil aggregation by adding organic matter to the top soil, (ii) protecting soil aggregates from raindrop impact, and (iii) preventing soil compaction caused by raindrop impact [42,4]. When determining soil structural stability, the ability of soil aggregates to remain intact when under stress is a relevant indicator. Soil porosity, water, gas, and nutrient transport through the soil system, and root development are all influenced by soil aggregates and their stability [4]. Researchers found that year-round no-tillage (NT-NT) and one-seasonal no-tillage followed by conventional tillage (NT-CT)

treatments with crop residues left on the surface had significantly higher water-stable macroaggregates in the surface soil layer (0-15 cm) than year-round conventional tillage (CT-CT) and one-seasonal conventional tillage followed by no-till-age treatments (CT-NT) where residues were incorporated in soil. Higher SOC concentrations on the soil surface were attributed to improved soil aggregation in the NT-NT and NT-CT treatments [43]. It could be explained by the fact that in the absence of tillage, increased crop residual biomass on the surface resulted in slower biomass integration and breakdown, and therefore more stable aggregation and SOC accumulation in the surface [44]. Experiment findings on the use of agricultural residues as compost for enhancing soil physical qualities reported by [45] found that maize stover compost had the highest total porosity (49.05%), followed by rice straw compost (47.87%). (43.23%). Experimental findings of rice-wheat cropping system revealed that incorporation of straw + NPK increased total soil porosity (46.30%) and decreased the bulk density ( $1.42 \text{ Mg m}^{-3}$ ) in 0-15 cm soil layer when compared to 100% NPK treated plots (43.10%,  $1.51 \text{ Mg m}^{-3}$ , respectively) [46]. No-till combined with residue retention has been demonstrated to be a viable strategy of minimizing soil compaction in Africa's humid and subhumid regions [47]. Physical soil protection against water loss can also be provided via residue retention on the soil surface. Furthermore, crop leftovers reduce the amount of debris in surface runoff after rains [48]. [49] found considerable runoff and soil loss under No-Till (NT) without residues, significantly less under NT with  $2.0 \text{ t ha}^{-1}$  of surface soybean residue, and no runoff or soil loss under NT with  $4.0 \text{ t ha}^{-1}$  of surface soybean residue in a crop management experiment in southwestern Brazil. In NT with surface residue, water infiltration rates were also greater [50]. The large water and soil losses from NT without surface residue were most likely attributable to soil hardening produced by rain impact in the absence of ground cover, which increases surface runoff and reduces water infiltration [51]. The significant runoff and soil loss levels in the disk-harrow treatments with  $2.0$  and  $4.0 \text{ t ha}^{-1}$  of soybean residue, which were absorbed rather than left on the soil surface, underscored the protective effect of residue retention on the surface [49]. When compared to furrows without surface residue and CT without surface residue, soil loss and runoff were significantly lower in permanent raised beds with 30% standing stubble. This was explained by increased aggregate stability and the mulching

effect of the standing stubble, consistent with the results of [52]. The main benefit of surface residue cover in terms of yield growth under rainfed climatic circumstances where crop production is limited by soil moisture is moisture retention. In drought-prone locations, residue retention has been shown to decrease runoff and minimize evaporation, resulting in increased soil water content and resilience [53]. Infiltration rates for zero-tillage under full irrigation can be significantly higher than for traditional tillage because residues inhibit surface compaction and sealing [54]. Increased soil temperature and aeration, as well as enhanced contact between microorganisms and residues, result in higher breakdown rates and overall SOC loss when crop residues are incorporated into the soil [55,56].

### 3.2 Soil Chemical Properties

The main component of soil fertility, productivity, and quality is soil organic matter (SOM). SOM decline is thought to have a slew of negative consequences on crop productivity [57,58]. Because it increases soil aggregate stability, soil water retention, and offers a store of soil nutrients, soil organic matter (SOM) is regarded as an important indication of soil quality and agricultural sustainability [59]. Climate, particularly yearly precipitation and temperature, as well as cropping methods, are the primary determinants of SOM storage in agricultural soils. The effect of soil organic carbon (SOC) on soil structure, water holding ability, soil buffering capacity, and as a source of plant nutrients has an impact on productivity. In reality, a stable soil structure is a requirement for a healthier soil physical environment. The loss of organic matter has a negative impact on the soil quality and crop output. The amount of organic matter in soil is determined by the inputs of plant, animal, and microbial wastes, as well as the rate of breakdown of both additional and existing organic matter through mineralization. Heterotrophic microbes are primarily responsible for the decomposition of organic materials. Temperature, moisture, and ambient soil conditions influence this process, which results in the release and cycling of plant nutrients, particularly N, S, and P [60]. [61] studied the effect of crop residue management in a rice-wheat cropping system during the kharif and rabi seasons, finding that the highest organic carbon content ( $4.80 \text{ g kg}^{-1}$ ) was obtained with 100 percent RDN +  $20 \text{ kg ha}^{-1}$  of N added through crop residues, while the lowest was obtained with

100 percent RDN +  $20 \text{ kg ha}^{-1}$  of N added through crop residues ( $3.80 \text{ g kg}^{-1}$ ). [62] investigated the short and long-term effects of rice straw application on flooded and upland soil conditions and found that continuous rice straw application @  $5 \text{ Mg ha}^{-1} \text{ year}^{-1}$  for 12 years increased soil total C content ( $21.60 \text{ mg g}^{-1}$ ) when compared to no rice straw application ( $18.20 \text{ mg g}^{-1}$ ). The addition of crop residues can affect the availability of nitrogen to the crop N mineralization can occur when legume residues with a low C/N content are added, but cereal residues with a high C/N content can temporarily immobilize N during the decomposition process [63]. Denitrification losses of mineral nitrogen fertilizer might be increased if residues are left on the surface and fertilizers are not effectively absorbed [64]. After five years of straw management in wheat-rice, [65] found that the largest soil build-up of accessible N ( $150 \text{ mg kg}^{-1}$ ), P ( $15.40 \text{ mg kg}^{-1}$ ), and K ( $73.00 \text{ mg kg}^{-1}$ ) was observed under straw incorporation above inorganic fertilizer treated plots ( $120.4 \text{ mg kg}^{-1}$  N,  $12.60 \text{ mg kg}^{-1}$  P and  $49.70 \text{ mg kg}^{-1}$  K, respectively). Crop residues considerably boosted the availability of nitrogen ( $173 \text{ kg ha}^{-1}$ ), phosphorus ( $57.80 \text{ kg ha}^{-1}$ ), potassium ( $157 \text{ kg ha}^{-1}$ ) and sulphur ( $35 \text{ kg ha}^{-1}$ ) in a loamy sand soil in Punjab when compared to 100 percent NPK alone ( $139, 38.90, 113, \text{ and } 22.40 \text{ kg ha}^{-1}$ ) [66]. DTPA extractable Zn, Cu, Mn, and Fe were significantly higher in the crop residues incorporated treatment than in the no residues incorporated condition [67]. Retention of crop residues can affect soil pH and electrical conductivity since the direction of change in soil pH and electrical conductivity are related to the chemical composition of the residue and soil properties [68]. Furthermore, soil parameters such as texture, moisture content, temperature, available N, SOC, and beginning pH are controlling factors for the effect of crop residues on soil pH [69]. The concentration of organic anions in the residue and the nitrogen content of that residue are connected to changes in pH caused by crop residue addition [68]. The pH of all organic treatments declined from 7.8 to 7.4 due to the release of organic acids during the decomposition of organic compounds, according to [70]. Cattle manure treatment yielded the lowest pH, followed by animal manure mixed with wheat straw. [66] found that when organic sources (green manure + soil NPK) were added to a long-term experiment on rice-wheat cropping systems, soil pH ( $7.60$ ) and EC ( $0.36 \text{ dSm}^{-1}$ ) declined little compared to initial pH and EC values ( $7.15$  and  $0.28 \text{ dSm}^{-1}$ , respectively).

### 3.3 Soil Biological Properties

Soil microflora (bacteria, fungi, mycorrhiza, actinomycetes, etc.) and fauna are subdivided into microfauna (Nematodes, protozoa, etc.), mesofauna (e.g., ascarids, enchytraeus), and macrofauna (e.g., earthworms, termites, large arthropods). These species can also be defined in terms of soil food webs, which include microflora and microfauna that break down organic matter, mesofauna that eats them, and macrofauna that eats mesofauna [71]. Soil microbes decompose organic matter, which influences water and nutrient availability as well as soil structure in agroecosystems. In a rice-wheat cropping system, maximum bacterial ( $78.2 \times 10^6 \text{ g}^{-1} \text{ soil}$ ) and fungal ( $63.5 \times 10^6 \text{ g}^{-1} \text{ soil}$ ) activity was observed in the treatment that received 100 percent RDN +  $20 \text{ kg ha}^{-1}$  of N added through crop residues, compared to the control ( $32.4 \times 10^6$  and  $17.2 \times 10^6 \text{ g}^{-1} \text{ soil}$ , respectively) [61]. Results have shown that higher microbial diversity and activity in residue retention systems, with bacteria dominating and as the residue decomposes, the fungal community tends to increase, and the bacteria/fungi biomass ratio decreases. Because of their association to soil biology and rapid responsiveness to changes in soil management, soil enzymes are one of the most important factors in agriculture for their role in nutrient cycling. They are also considered early markers of specific biochemical reactions in soil [72,73]. The biological markers of soil health are soil enzymes. Enzymes are crucial components of the soil ecosystem because of their interactions with plants, nutrients, and organic matter cycling [74]. Dehydrogenase activity is expected to reflect the whole range of oxidative activity of soil microflora and thus may be regarded a good diagnostic of microbial activity because it is only found in live cells. In general, the amount of organic matter in the soil affects the enzyme activity. The living element of soil organic matter is known as soil microbial biomass (SMB) [75]. Another helpful and sensitive indicator of soil quality has been proposed [76]. The use of balanced amounts of fertilisers and manures enhanced the organic matter and MBC status of soils, resulting in increased enzyme activity. The quantity and amount of nutrients added increased dehydrogenase activity and microbial biomass in a proportionate manner [77,78]. In comparison to the approved amount of fertiliser, rice straw compost @  $5 \text{ t ha}^{-1}$  plus half of the necessary dose of inorganic fertiliser boosted dehydrogenase activity ( $66 \text{ mg TPF kg}^{-1} \text{ soil } 24$

$\text{h}^{-1}$ ) ( $93 \text{ mg TPF kg}^{-1} \text{ soil } 24 \text{ h}^{-1}$ ) [79]. After two crop cycles, crop residue assimilation resulted in considerably higher dehydrogenase activity in silty clay loam soil ( $65 \text{ g of TPF g}^{-1} \text{ soil } 24 \text{ h}^{-1}$ ) than 100 percent NPK in wheat ( $60 \text{ g of TPF g}^{-1} \text{ soil } 24 \text{ h}^{-1}$ ) [80]. [81] found that green manuring and crop residue integration resulted in positive and substantial variations in biological characteristics in terms of dehydrogenase and alkaline phosphatase activities. When comparing 75 % RDF with crop residue to 75 % RDF alone, the treatment with crop residue had the highest dehydrogenase activity ( $4.60 \text{ mg TPF kg}^{-1} \text{ soil } 24 \text{ h}^{-1}$ ) and phosphatase activity ( $7.40 \text{ mg PNP kg}^{-1} \text{ soil } 24 \text{ h}^{-1}$ ) ( $25.00 \text{ mg TPF kg}^{-1} \text{ soil } 24 \text{ h}^{-1}$  and  $3.80 \text{ mg PNP kg}^{-1} \text{ soil } 24 \text{ h}^{-1}$ , respectively).

### 4. CONCLUSION

Plant nutrition and soil health management rely heavily on crop residues from popular agricultural crops. Crop residue management necessitates an in-depth study of the elements that influence residue breakdown, as well as their cautious use in various cropping systems. Food security and environmental development are dependent on soil carbon stocks, which can be sustained in agroecosystems through improving crop residue recycling procedures. Crop residue recycling in agriculture can be both cost-effective and helpful to soil fertility and crop yield. Crop residues minimising soil degradation and boosting soil fertility and productivity, improved residue management and decreased tillage practices may be encouraged. Burning crop wastes should be avoided for environmental reasons and to replenish the earth's organic carbon pool.

### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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