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Crop Residue Management: For Sustainable Agriculture

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1. Introduction

Crop residue means materials remaining in an agricultural field after the crop has been harvested. These byproducts include stalks, branches, leaves, and seed pods (Kaur et al., 2019). Burning crop leftovers is, in general, a simple, practical, and cost-effective way to manage in-situ crop waste. This practice also saves a lot of time while clearing the fields for farming. For farmers, there is not much time between harvesting one crop and planting the next. Even though these management practices have produced several challenges, including environmental and health effects. However, extensive research on cropping systems has largely found that nutrient-rich crop residue combined with inorganic fertilizer increases soil health and production. Crop wastes can be reused in agriculture in a variety of ways, including direct incorporation, mulching, composting, vermicomposting, etc. It is also used as dry animal feed, in biothermal power plants, for growing mushrooms, as cattle fodder, to make bio oil, paper, and biogas (Rajput et al., 2017). Due to the excessive use of chemical fertilizers and pesticides as well as contemporary farming techniques, soil fertility and production decline day by day. Utilizing organic wastes as a soil amendment has the potential to significantly improve soil quality, crop yield, and soil health while also helping to solve the problem of waste disposal. Most of the rice straw is used as an organic waste product whose maximum amount requires a small amount of beneficial disposal solution (Swarnima S and Vinay A., 2018).

Every year, around 500 Mt and 116 MT of crop residues were produced and burned, respectively. The generation of crop residues is Uttar Pradesh, Punjab and Maharashtra was 60, 51 and 46 Mt, respectively. Cereals provide the most residues (352 Mt) among different crops, followed by fibres (66 Mt), oilseeds (29 Mt), pulses (13 Mt), and sugarcane (12 Mt). The cereal crops (rice, wheat, maize, and millets) account for 70% of the crop residues, with the rice crop alone providing for 34%. Wheat comes in second with 22% of agricultural residues, while 13% of crop residues are produced by fiber crops.

Burning crop residues causes a variety of environmental problems, such as soil erosion, water contamination, poor air quality, and GHG emissions. The soil's fertility and characteristics are negatively impacted by in-situ crop residue burning. Burning agricultural residue produced 149.24 million tons of CO_2, over 9 million tons of CO, 0.25 million tons

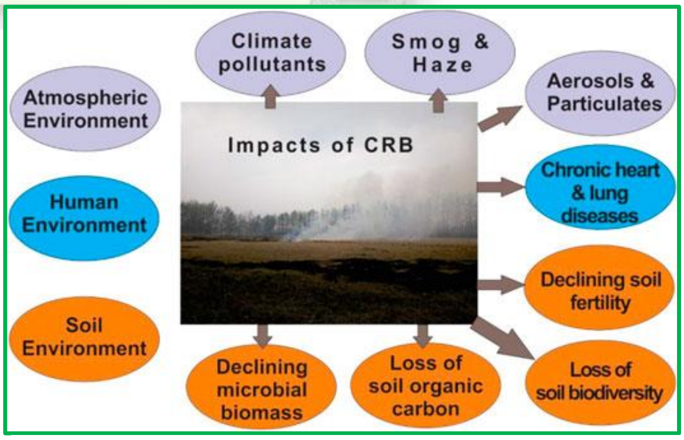

Fig. 1: Effect of crop residues Burning.

of SO_X, 1.28 million tons of particulate matter, and 0.07 million tons of black carbon. One centimeter of soil is heated by burning paddy straw, bringing the soil's temperature up to 33.8 to 42.2 degrees Celsius. one ton stubble burning leads to a loss of 5.5 kg nitrogen, 2.3 kg phosphorus, 25 kg potassium and more than 1 kg of sulfur all soil nutrients, besides organic carbon. The bacterial and fungal populations essential for a fertile soil are eliminated. The soil's physical, chemical, and biological properties may be impacted by crop residues (Kaur et al., 2019). They improve the soil's levels of organic carbon, total nitrogen, and microbial biomass. The burning of crop wastes in the field results in the loss of nutrients including carbon, phosphate, and nitrogen by volatilization.

2. Management of crop residues

Farmers have several management alternatives at their disposal for the profitable management of agricultural residues, including livestock feed, mushroom cultivation, incorporation, surface retention and mulching, and removing the straw. Depending on the situation, farmers employ a variety of straw management techniques.

2.1. **As livestock feed:** In India, crop residues such as wheat and paddy straw are traditionally used as animal feed, either alone or in combination with other ingredients. It is possible to improve the nutritional content of rice straw in a variety of ways. Crop residues' ligno-cellulose linkages have been reduced and decomposed using physical, chemical, and biological processes to increase their nutritional value. About 75% of wheat straw is used as animal feed, chopped into small bits with the aid of specialized cutting equipment. However, this necessitates more work and expenditure. The rice crop should be cut as close to the ground as feasible if the straw is to be fed to livestock, since rice straw stems are more digestible than leaves due to their reduced silica concentration (Kamla *et al*. 2015).

2.2. **Composting:** Composting is the natural rotting or decomposition of organic waste by microorganisms under regulated conditions (Misra, R.V et al., 2003). Compost, which is a rich source of organic matter, is crucial for maintaining soil fertility and promoting sustainable agricultural output. Composting the soil enhances its physical, chemical, and biological qualities and can entirely replace the need of agricultural chemicals like fertilizers and insecticides. The advantages of compost enriched soil include greater potential for increased yields and tolerance to outside forces including drought, disease, and toxicity (Lei *et al*., 2010).

Fig. 2: Composting of crop residues

2.3. **Mulching:** The positive effects of this practice to increase crop yields at comparable irrigation regimes and save irrigation water and fertilizer nitrogen at comparable yields in several wide row crops, including maize, sugarcane, sunflower, soybean, cotton, turmeric, potato, and chilies. This is done by reducing the evaporation (E) component of the ET and acting as a barrier to vapor flow and regulating soil temperature. Rice straw mulch increased wheat grain yield in respect to no mulch, decreased crop water uses by 3–11%,

Fig. 3: Rice straw mulches in Potato

and increased water use efficiency by 25%. When compared to no mulch, root length densities were 40% greater because mulch kept soil moisture at deeper levels. The use of rice residue management in no-till systems has several advantages, including the retention of soil moisture, the control of weeds, improved soil quality, and a decrease in greenhouse gas emissions of nearly 13 t/ha. It also regulates canopy temperature at the grain-filling stage to lessen the effects of terminal heat on wheat.

2.4 **Baling/Binder for domestic or industrial fuel:** Agricultural straw can be used for a variety of purposes, including mulching cucumbers, melons, and other vegetable orchards and other crops, as well as for livestock bedding, fuel, construction materials, and mushroom composting. Straw baler machines, which are commercially available, are a promising technique for removing and collecting straw after combines harvesting and using the wastes for off-farm uses. However, depending on the height of the plant chopped, these balers only recover 25 to 30% of the potential straw production after combining. Straw for making round or rectangular bales is collected by balers from the ground. Approximately 200–250 bales with a 460–360 mm bale size, weighing between 15 and 30 kg, are being recovered by the machine from a mixed harvested field (depending on moisture content and field conditions). In combine harvested fields, the operating speed might range from 2-3 km/h depending on the field conditions. The operational cost per acre is Rs. 6170, and the energy requirements range from 0.6 to 1 kW h/t. It can also be used for engineering purposes; mushroom cultivation; bioconversion; and paper and bioethanol processing after crop residues have been baled (Meena et al., 2022).

Fig. 4: Straw baler.

Fig. 5: Happy seeder

Fig. 6: Straw mulching in wheat

Fig. 7: Biochar production using rice stubble

2.5. **Direct seeding by zero tillage and happy seeder:** Happy Seeder-based systems are 10–20% more profitable than burning, making them the most effective and scalable method for managing residue. This option has the greatest potential to lessen the environmental impact of operations on farms when compared to all other burning options because it would eliminate air pollution and cut greenhouse gas emissions per acre by more than

78%. This happy seeder helps in spreading and pressing the chopped paddy straw in the interrow field as a mulch, which encourages improved germination, emergence, and a vigorous response to the initial establishment. With the help of a happy seeder machine, wheat can be directly sown in the combine harvester rice field (7-9 tons per hectare straw). This equipment has a 45-horsepower tractor capacity and can move 0.6-0.75 acres per hour. It costs roughly Rs. 125,000/-.

2.6. **Biochar**: Biochar is a fine-grained, porous substance made by pyrolysis, a thermochemical process that takes place at low temperatures without oxygen (Amonette, et al., 2009). It is a mixture of varying amounts of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulphur (S), and ash (Masek, et al., 2019). The very porous characteristic of biochar when added to soil helps with greater soil surface area and better water retention. This has increased interest in using soil amendments like biochar, charcoal, and black carbon to stabilize soil organic content. These methods are seen to be a good choice for reducing GHG emissions while also significantly lowering the amount of agricultural waste. Increased residence time and resistance to chemical oxidation of biomass into CO_2 or reduction into methane, which results in a reduction of CO_2 or methane emission to the environment, are basically requirements for the carbon sequestration process (Dhar et al., 2014; Hesammi et al., 2014).

Fig. 8: Management of crop residues

3. Effect of surface crop residues on soil water processes

The crop water balance is determined by the impact of soil water evaporation, soil water infiltration, and water runoff on three primary soil water processes.

3.1. **Soil water evaporation:** Crop residue mulches help to minimize the overall amount of soil water evaporation throughout the growing season. The boundary line's maximum influence on the amount of surface residues on soil water evaporation was a reduction of about 30% compared to bare soil, which is attained with 8 t/ha of residues or more. As the percentage of soil covered with residues increased, there was a general trend toward less soil water evaporation. Surface crop residues offer complete soil protection and prevent less sunlight from entering the soil, which lowers soil water evaporation losses. When the soil is moist and the leaf area of growing crops is low, a mulch made of crop residues works better to reduce soil water evaporation (Singh et al. 2011).

3.2. **Soil water infiltration:** Surface residue deposition used to have a significantly distributed impact on soil water infiltration. An increasing percentage of soil was being covered with residues, and this trend was generally one of an increase in soil water infiltration rate. As compared to bare soil, a completely covered soil can improve soil water infiltration fourfold. The rate of soil water infiltration rises as a result of residue cover, which deflects some of the rain, reducing soil crusting and soil losses through runoff. By increasing soil aggregate stability and porosity, residues and the byproducts of their breakdown improve the structure of the soil which also improves the soil water infiltration rate. The presence of mulch may restrict water infiltration by the addition of water repellent and hydrophobic properties to the soil surface. It is essential to emphasize that a host of new variables, including slope, soil hydraulic conductivity, vegetation density, and rainfall quantity and intensity, greatly impact the relationship between soil water infiltration and surface wastes (TerAvest et al. 2015).

3.3. **Soil water runoff:** With an increase in residue quantity, surface residues became more effective at reducing water runoff. When compared to the quantity of residues rather than the percentage of soil covered, the spread of observations on soil water discharge as a function of residue mulch was lower. In order to increase rainwater infiltration and decrease water runoff, surface crop residues protect soil against structural degradation of the surface. Due to increased soil surface roughness and restriction of runoff channels, residue cover enhances the time before runoff begins and reduces runoff flows. It reduces surface crusting, enhances aggregate stability, and protects the topsoil's physical structure (Jordán et al. 2010).

3.4. **Effect of surface crop residues on soil erosion:** Soil erosion dramatically decreased with increasing surface crop residues. Compared to bare soil, soil erosion was reduced by nearly 80% at residue levels of 2 to 4 t dry matter/ha. Almost all soil loss stops at 8 t of dry matter/ha of residues and higher. The amount of soil detachment is decreased by residue cover because it dissipates the energy of raindrops and reduces runoff flows. In addition to enhancing aggregate stability and reducing surface crusting, it protects the topsoil's physical structure. The efficiency of residue cover in controlling soil erosion is highly dependent on rainfall intensity. The type of residue has an impact on how well residue cover controls soil erosion. Wheat residues are the most effective at preventing soil erosion because they have a larger area-to-mass ratio than maize, rye, or rice residues (Jordán et al. 2010).

3.5. **Effect of surface crop residues on soil nutrient availability:** Increasing the amount of surface residues is related to improving the nutritional content of the soil because residue decomposition releases nutrients into the soil. By releasing mineral N to the soil, residue decomposition influences how much N is available to crops. Nitrogen is temporarily immobilized in grain residues with a high C to N ratio, but nitrogen is mineralized in legume residues with a low C to N ratio (Govaerts et al. 2006). Phosphorus (P) will be more readily available in the topsoil through mineralization if crop residues are left on the field (Feng et al., 2014). Compared to bare soil, surface crop residues enhanced the exchangeable soil K content. A temperate climate showed greater efficacy of residue cover in improving soil exchangeable K than a tropical one. Since crop residues are known to be high in potassium, they are expected to be a significant source of soil potassium when left on the soil (Lupwayi et al. 2006).

3.6. **Effect of surface crop residues on soil organic carbon:** As residue concentrations increased, so did SOC stocks. The soil's structure and texture play a major role in SOC storage. SOC is stabilized to a significant extent by the finer soil components (clay and silt). since clay soils tend to have higher SOC stocks than sandy soils.

3.7.**Effect of surface crop residues on weed infestation:** By changing soil moisture, the amount of light that reaches the soil surface and the leaves of weed seedlings, as well as by an allelopathic effect, residue cover can affect weed emergence and biomass. Generally, weed emergence reduced as residue amounts increased. Surface crop residues produce microenvironments that either restrict or promote weed germination. Crop residues can hinder weed emergence physically or by changing the soil's conditions. Weed emergence may be prompted by an increase in topsoil moisture brought on by the presence of surface crop residues. Rapid residue decomposition causes a swift reduction in soil cover and, by raising soil fertility, may encourage weed emergence. The light, temperature, and moisture conditions of a soil are influenced by residues left on the soil, which has an impact on weed biomass (Teasdale and Mohler 1993). The effectiveness of weed management through mulching is dependent on both the type of residue and the species of weeds, in addition to the amount of residue.

3.8. **Effect of surface crop residues on soil meso and macrofauna abundance:** As surface residues increased in quantity, so did the variety of fauna. However, the increases in soil fauna in response to rising residue levels were rather negligible. Organic matter from residue cover serves as a food source for soil organisms. However, the increases in soil fauna in response to rising residue levels were rather negligible. As indicated by the boundary line, soil fauna can be increased by a maximum of 30% over bare soil using 5 t dry matter ha^{-1} of surface residues.

3.9. **Maximum effects of crop residue cover:** The maximum possible impact of increasing surface crop residue amounts on soil water retention and nutrient availability was negligible. The abundance of meso- and macrofauna only moderately responded to the accumulation of surface agricultural wastes. On the other hand, surface crop residues had a sizable potential impact on soil water infiltration, water runoff, and the management of soil loss. The recommended standard for a minimum soil cover of 30% in the practice of conservation agriculture is in line with the threshold value of 2-3 t ha1 of residues to obtain the maximum influence on these expected agro-ecological functions. A maximal response was seen for both weed emergence and biomass control from 4 t/ha of residues. As the amount of mulch increases, the SOC stock rises.

4. Conclusion

Crop residue recycling has the huge potential to supply the soil with a significant amount of plant nutrients. Consequently, managing crop residues properly and efficiently is a significant problem for agriculturalists in order to improve carbon sequestration and maintain the sustainability of production. This residue boosts nitrogen mineralization and SOC. On the physical, chemical, and biological characteristics of soil, the residue has various impacts. The availability of soil nutrients (N, P, and K) and SOC stocks responded only moderately to higher residue concentrations. Surface residues may have a greater role in improving soil water processes, particularly water runoff and soil erosion control, but mulching in low-input systems is likely to play a greater role in improving soil fertility by preserving or building up SOC stocks. Various methods can be utilized, as indicated above, depending on the type of residue and the climate.

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