Cropresiduesmanagementoptioninrice-wheatcropping system:Areview

Abstract

The dominant agricultural system in India is the rice-wheat system, and the problems posed by climate change and declining soil health are endangering the system's sustainability. High yields from the irrigated rice-wheat system have resulted in a substantial amount of wasted food. In northwest India, burning rice straw is a frequent practice that results in significant air pollution that is harmful to human health and nutritional losses. Crop residue management improvements should help achieve sustainable productivity, enable farmers to minimize nutrient and water inputs, and lower the risk associated with climate change-all of which will help prevent straw burning. The rice-wheat system's nutrition management will benefit from the prudent application of crop residues, which contain substantial amounts of plant nutrients. Long-term research on residue recycling has shown improvements in the soil's chemical, biological, and physical health. Another viable approach to managing crop residues is to use some of the excess residues to make biochar, which can be added to the soil to enhance its health, maximize its ability to use nutrients, and reduce air pollution. Mushroom cultivation may convert non-edible crop leftovers into a nutritious food source, surface mulch can suppress weed growth and retain soil moisture, and compost and biofuel can all be made from these materials. Decomposition of residues considerably boosts the soil's organic carbon and nitrogen levels. This review looks at the residues that can form in a rice-wheat farming system and how those residues can be effectively managed.

Keywords:*Rice-wheatsystem, Sustainable agriculture,plantnutrients, Soil health*

Introduction

Plant remnants are portions of the crop that remain in the field following harvest and threshing. The benefit of recycling agricultural wastes is that they can be used to make valuable products that will help future crops satisfy their nutrient needs. Crop residues provide plant nutrients and serve as a source of organic C for soil microbes. Retaining crop residue on the soil's surface can lower land preparation expenses and runoff/erosive soil by a significant amount. It can also reduce soil evaporation. (Lal, 1989). Crop residues amount to 500–550 million tons (Mt) produced yearly in India. The MoA, 2012, One of the most extensively used cropping systems in India is the Rice Wheat Cropping System (RWS), with the Indo-Gangetic Plains (IGP) accounting for 90% of the country's total area (Janaiah and Hossain, 2003). Over seventy-five percent of the rice field in the region northwest of the IGPs is harvested mechanically thanks to the use of combine harvesters.In order to feed the animals, most farmers remove the wheat straw. However, because of its high silica concentration, rice straw is thought to be a poor animal feed, making management a significant difficulty. The seed drill is impeded in its capacity to sow wheat by the vast path of loose rice remnants left behind by the combine harvester. To avoid these problems, farmers burn off their agricultural waste, which amounts to 90-140 Mt per year. If farmers are looking for a cheap and effective strategy to get rid of pests, burning rice straw is likely the best solution (Dobermann & Fairhurst, 2002). According to estimates from Gadde et al. (2009), burning rice straw is responsible for 0.05% of India's total emissions of greenhouse gases (GHGs). This contributes to the loss of massive amounts of biomass, or organic carbon and plant nutrients, as well as negative effects on the flora and fauna that live in the soil. Therefore, strategies and tactics for managing this priceless resource must be implemented. This page discusses crop residue potential, available management strategies, soil features related to residue management, and other related topics.

Cropresiduespotential

An estimated 500 million tonnes of crop leftovers are produced annually, according to estimates from the Indian government's Ministry of New and Renewable Energy (2009). The state of Uttar Pradesh produces the most crop leftovers (60 Mt), followed by Punjab (51 Mt) and Maharashtra (46 Mt). The largest amount of leftovers among the various crops is produced by grains (352 Mt), which are followed by fibers (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; the rice crop alone accounts for 34%, and wheat comes in second with 22% (Fig. 1).

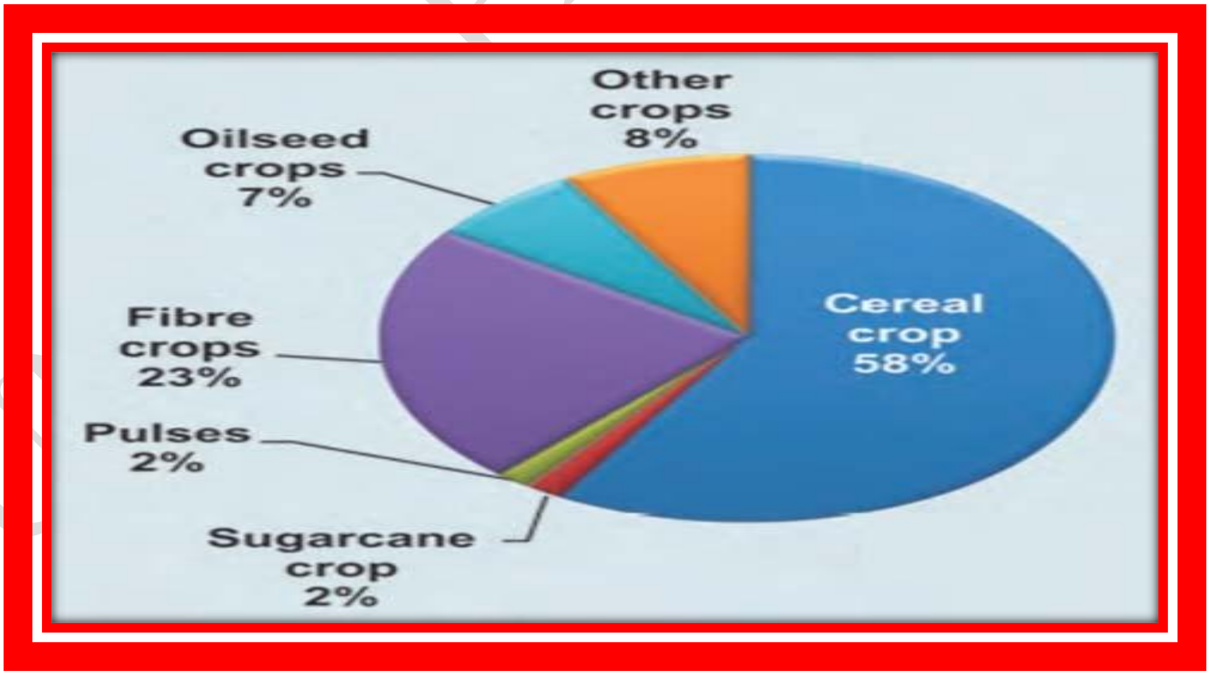

Fig1: Using data from MNRE (2009), we may estimate the percentage of India's crop wastes that go unused.

In India, the rice-wheat system produces around one-fourth of the agricultural residues, according to Sarkar et al. (1999). The majority of uses for the residue produced are as home and industrial fuel, animal feed, packing, bedding, in situ incorporation and manuring, thatching, and field burning. Nevertheless, about all of the residue produced during combine harvesting is left in the field and is ultimately burned.The double cropping technique is significantly reducing the amount of nutrients in the soil because both wheat and rice are heavy eaters of nutrients. According to Dobermann and Fairhurst (2002), there were 5-8 kg of nitrogen in one tone of rice straw. According to Singh and Singh (2001), more than 300 kg N, 30 kg P, and 300 kg K ha^{-1} are lost from the soil throughout a rice-wheat sequence that yields 7 t ha^{-1} of rice and 4 t ha-1 of wheat. Gupta et al. (2002) offer an additional estimate, suggesting that 730 kg of NPK are removed from the soil to produce a crop yielding 10 t ha^{-1}, and that this amount is not always replaced. This might result in soil being mined for important nutrients, which would put crops at risk for multi-nutrient deficits and a net negative balance. This is one of the causes of the decrease in rice-wheat system yield. In order to maintain the stability of the system and the sustainability of the soil health, it is imperative that the residues from these crops be managed.

Cropresiduesburning

India, a nation dominated by agriculture, generates more than 500 million tons of crop residues annually. A significant amount of these unutilized crop residues are burned in the fields to remove leftover straw and stubbles that obstruct tillage and the process of seeding a subsequent crop. The increased use of combines during harvest, a shortage of available labor, and the high cost of removing crop leftover from the field are major contributors to the widespread practice of burning crop wastes in the fields. N (up to 80%) P (up to 25%) K (up to 21%) and S (up to 60%) are all lost in high concentrations when crop residues are burned (Raison, 1979) (Ponnamperuma 1984). In addition to killing viruses and pests, this approach also significantly reduces soil microbial mass and pollutes the air. The burning of wastes results in a loss of soil organic matter, which poses a clear threat to the long-term viability of the rice-wheat system.

Adverse effects of residue burning:

Burning paddy straw, also known as stubble burning, is a common agricultural practice with adverse effects on the environment, human health, and sustainable agriculture. This practice involves setting fire to the leftover crop residue after harvesting paddy fields. While it may seem like a quick and inexpensive way to clear fields for the next planting season, the consequences are far-reaching and detrimental. In this essay, we will explore the adverse effects of burning paddy straw in detail.

1. **Environmental Impact**:

The most immediate and noticeable consequence of paddy straw burning is air pollution. The combustion of crop residues releases a significant amount of pollutants into the atmosphere. These include particulate matter, carbon monoxide, nitrogen oxides, sulfur dioxide, and volatile organic compounds. The inhalation of these pollutants can cause respiratory problems and exacerbate existing conditions such as asthma. Moreover, these pollutants contribute to the formation of smog, which not only reduces visibility but also has long-term effects on air quality.

2. **Soil Health Degradation**:

Burning paddy straw eliminates valuable organic matter that could enhance soil fertility. Crop residues play a crucial role in maintaining soil structure, moisture retention, and nutrient cycling. When burned, these residues are lost, leading to soil degradation. This degradation can result in decreased agricultural productivity over time, as the soil becomes less able to support healthy plant growth.

3. **Loss of Biodiversity**:

The practice of burning paddy straw also affects biodiversity. The intense heat and smoke from burning can harm or kill beneficial insects, microorganisms, and other small organisms in the soil. Additionally, the loss of habitat and food sources due to this practice can disrupt local ecosystems, potentially leading to a decline in biodiversity.

4. **Contribution to Climate Change**:

Paddy straw burning is a significant source of greenhouse gas emissions. The release of carbon dioxide and other greenhouse gases during combustion contributes to global warming and climate change. Given the increasing concerns about climate change, continuing the practice of burning paddy straw is incompatible with global efforts to reduce carbon emissions and mitigate climate change.

5. **Impact on Human Health**:

Apart from immediate respiratory issues caused by air pollution, the long-term impact of burning paddy straw on human health is a serious concern. Exposure to air pollutants from stubble burning has been linked to respiratory diseases, cardiovascular problems, and other health issues. Vulnerable populations, such as children and the elderly, are particularly at risk.

6. **Economic Consequences**:

While burning paddy straw may seem like a cost-effective method for farmers to clear their fields quickly, it has long-term economic consequences. The degradation of soil health and reduced agricultural productivity mean that farmers may face declining yields over time. Additionally, the health impacts on communities surrounding agricultural areas can lead to increased healthcare costs.

7. **Alternatives and Solutions:**

To mitigate the adverse effects of paddy straw burning, it is essential to promote and adopt alternative practices. One such method is the incorporation of crop residues into the soil through plowing or using modern agricultural machinery. Governments and agricultural extension services can play a crucial role in educating farmers about these alternative methods and providing incentives for their adoption.

Carbon credits viz-a-viz crop residue burning issues:

Carbon credits and crop residue burning are intricately linked through the concept of carbon emissions and the impact of agricultural practices on climate change. While carbon credits offer a potential avenue for mitigating the environmental consequences of crop residue burning, there are complexities and challenges in establishing this connection.

1. Understanding Carbon Credits:

Carbon credits are a market-based approach to reducing greenhouse gas emissions. They represent a unit of measurement equivalent to one ton of carbon dioxide (or its equivalent) that has either been reduced or offset. Carbon credits are tradable, allowing organizations or countries to buy and sell them to meet emissions reduction targets.

2. Crop Residue Burning and Greenhouse Gas Emissions:

Crop residue burning, a common agricultural practice, contributes significantly to greenhouse gas emissions. When farmers burn residues like crop stubble or straw, it releases carbon dioxide, methane, and other pollutants into the atmosphere. This practice exacerbates global warming and air pollution, impacting both climate and human health.

3. The Potential Role of Carbon Credits:

One potential solution to address the environmental impact of crop residue burning is to incentivize farmers through carbon credits. By adopting alternative practices, such as no-till farming or converting crop residues into bioenergy, farmers can reduce emissions. The avoided emissions or carbon sequestration resulting from these practices can be quantified, and farmers can earn carbon credits for the reductions achieved.

4. Challenges in Implementation:

However, the implementation of carbon credit programs related to crop residue management faces several challenges. Measurement and verification of emissions reductions can be complex, and there is a need for robust monitoring systems to ensure the legitimacy of claimed reductions. Additionally, the economic viability of carbon credit programs for individual farmers and the administrative burden of participation must be considered.

5. **Economic Incentives for Farmers**:

The linkage between carbon credits and crop residue burning can provide economic incentives for farmers to adopt more sustainable practices. Rather than burning residues, farmers can explore alternative methods that contribute to soil health and carbon sequestration. The income generated from selling carbon credits can supplement farmers' income and make sustainable practices more attractive.

6. **Government Policies and Support**:

Successful integration of carbon credits into addressing crop residue burning requires supportive government policies and programs. Governments can play a pivotal role in providing financial incentives, technical assistance, and creating an enabling environment for farmers to transition away from burning practices.

7. **Community and Stakeholder Engagement**:

Engaging local communities and stakeholders in the process is crucial. Farmers need to understand the benefits of sustainable practices both for the environment and their own livelihoods. Outreach programs, training, and collaborative initiatives can foster a collective commitment to reducing crop residue burning.

8. **Long-Term Environmental and Social Benefits**:

Ultimately, connecting carbon credits with alternatives to crop residue burning can yield long-term environmental and social benefits. It promotes sustainable agriculture, preserves soil health, reduces air pollution, and contributes to broader climate change mitigation efforts.

Hence, while the link between carbon credits and crop residue burning holds promise, its successful implementation requires a multi-faceted approach. Collaboration between governments, agricultural stakeholders, and the private sector is essential to create a framework that not only addresses the environmental impact of crop residue burning but also ensures the well-being and economic viability of farmers in the transition to more sustainable agricultural practices.

Alternative approaches for managing crop leftovers

India's rice-and-wheat cultivation method results in massive quantities of food waste. Many fields in North West India are left with residues after harvesting rice and wheat with combine harvesters. Cattle feed is the primary application for cereal crop leftovers. Both rice husk and straw are used as fuel in homes or boilers to parboil rice. Rice straw management is a major issue compared to wheat straw management because rice harvest and wheat sowing occur relatively close together, there is insufficient time for recycling, and rice has a greater silica content than other crops. Farmers have a number of alternatives for the profitable management of agricultural leftovers, including baling and removing the straw, incorporating, growing mushrooms, surface retention, mulching, and using biochar. Farmers employ a variety of straw management techniques depending on the circumstances.

1. **Using crop leftovers as animal feed**

In India, agricultural leftovers are traditionally used as animal feed, either alone or in combination with other additions. Nevertheless, crop leftovers cannot provide livestock with their whole diet because they are unpleasant and poorly digestible. Because rice straw contains a lot of silica, it is regarded as poor animal feed. It's different from other straws since it has a lower lignin content (6-7%) and a higher silica content (12-16%). There are a number of methods for improving the nutritional value of rice straw. The lignocellulose connections in crop wastes have been weakened and broken down utilizing physical, chemical, and biological treatments to boost their nutritional value (Sarwar et al., 2004). About 75% of wheat straw is used for animal feed, which requires extra time and money to prepare by chopping it into little pieces using a specialized cutting equipment. Since the stems of rice straw have a lower silica concentration than the leaves, they are more easily digested by animals, the rice crop should be cut as close to the ground as possible. To meet the animals' nutritional requirements, the wastes must be treated, improved with urea and molasses, and supplemented with green fodder (leguminous or non-leguminous).

2. Using crop waste as compost

Crop leftovers are heaped in dung pits and used as animal bedding to prepare compost. Every kilogram of straw that a cow sheds absorbs roughly two to three kilograms of urine, enriching it with nitrogen. About three tons of nutrient-rich manure can be produced from composting the leftover rice crop from one hectare of land. The rice straw compost can be reinforced with P utilizing a locally available supply of low-grade rock phosphate (Sidhu and Beri, 2005) to produce value-added compost with 1.5 percent nitrogen, 2.3 percent phosphorus oxide, and 2.5 percent potassium oxide.

3. Crop wastes for the production of mushrooms

Despite their high moisture content, mushrooms have two to three times the protein of common vegetables and an amino acid composition similar to that of milk or meat (Crisan and Sands 1978). The use of crop residues in the production of mushrooms represents a valuable conversion of inedible crop residues into valuable food. Agaricus bisporus (white button mushroom) and Volvariellavolvacea (straw mushroom) are two of the four most commonly cultivated fungus, and they both thrive on wheat and rice straws. Straw, which is frequently coupled with hay and horse dung in Agaricus production (Wuest et al. 1987, Maher 1991), allows for a very high substrate conversion efficiency into fungal bodies.

4. Using crop leftovers as biofuel

Without a question, using biofuel is a key tactic in the fight against fossil fuel dependency. Because ethanol may be used either alone in internal combustion engines or blended with gasoline to increase its fuel range and octane, the process of converting ligno-cellulosic biomass into alcohol is significant. Dry matter estimations for ethanol production from corn kernels, rice straw, wheat straw, bagasse, and sawdust range from 382.0 to 471.0 $l\ t^{-1}$. However, India is researching technology to create ethanol from agricultural byproducts. The process of turning crop leftovers into alcohol has a few steps that are restricting and could be improved.

5. Biochar made from crop leftovers

Crop wastes and biochar have garnered a lot of interest recently as a practical approach to preserving soil health. Precisely ground, high-carbon charcoal, known as biochar, is created by slowly heating biomass without oxygen, a process known as pyrolysis. It could be crucial for soil carbon sequestration over the long run. Biochar produced from plant biomass contains a type of carbon that is particularly resistant to breakdown by microorganisms when added to soil (Lemann and Joseph, 2009). Biochar can be used to store carbon because of this quality. In addition, research has shown that biochar can improve water quality by strongly absorbing contaminants (Spokas et al. 2009, Zhang et al. 2012), and it can reduce greenhouse gas emissions from agricultural lands. However, biochar's properties are highly variable, shifting both during and after pyrolysis, depending on the conditions and the biomass used (Jeong, 2015).

6. Assimilation of crop residue

Straw, as opposed to crop trash clearance or burning, can be added to soil to increase its organic matter and nutrient (N, P, and K) concentrations. Plowing is the most efficient method of integrating leftovers. It also improves soil quality and the duration of crop residue until the following crop is planted (Singh et al., 2005). The in situ incorporation of rice straw in soil 10, 20, or 40 days before to wheat sowing has not had a detrimental effect on the grain output of wheat or following rice, according to a six-year study conducted by Singh et al. (2001) and Singh et al. (2004). Not even the next rice harvest was affected in a significant way by the addition of rice straw to wheat.

7. Using crop waste as surface mulch

To mitigate soil degradation and minimize water loss owing to evaporation, the adoption of residue retention on the soil's surface emerges as a favorable approach. Furthermore, it serves to reduce the germination of weed seeds and enhance the development of soil microbial communities, hence increasing soil organic carbon levels, a distinct indicator of soil health. Zero-till wheat has been included into the rice-wheat system in the northwest Indo-Gangetic Plains (IGP) due to its positive impact on wheat productivity, profitability, and resource utilization efficiency (Erenstein and Laxmi, 2008; Ladha et al., 2009). Consequently, a novel and technologically improved seed drill has been designed. Sidhu et al. (2007) suggest that the utilization of the Happy Seeder will serve as a catalyst for the increased adoption of conservation agriculture practices. The Happy Seeder demonstrates efficacy as a direct drilling tool in the presence of both standing and loose residues, provided that the residues are uniformly dispersed. In comparison to a scenario without mulch, the application of rice straw mulch resulted in an increase in wheat grain production, a reduction in crop water consumption by 3-11%, and an improvement in water-use efficiency by 25%. At depths below 0.15 m, the application of mulch resulted in a 40% increase in root length densities compared to areas without mulch. This effect can be attributed to the enhanced retention of soil moisture in deeper layers, as observed in the studies conducted by Chakraborty et al. (2008, 2010).

CropResidueManagementandSoilHealth

Both rice and wheat are considered to be crops that require a substantial amount of nutrients for optimal growth. Consequently, one of the primary factors contributing to the degradation of soil health within the rice-wheat system is the excessive extraction of nutrients from the soil. Rice and wheat crops exhibit a greater capacity for nutrient extraction from the soil in comparison to the amount of nutrients introduced through fertilizers and recycling practices. The inclusion of residues has been found to enhance the physical, chemical, and biological characteristics of soil, as demonstrated by studies conducted by Beri et al. (1992, 1995) and Singh et al. (2008, 2005). The physical attributes encompass several characteristics such as soil structure, infiltration rate, plant accessible water capacity, nutrient cycling, cation exchange capacity, and soil pH **(**Singh et al., 2008; Beri et al., 1995; Bellakki et al., 1998; Singh et al., 2010).

1. **Impact on the physical health of the soil**

Crop residue management techniques have an impact on the physical characteristics of soil, including bulk density, porosity, aggregate formation, and moisture content. Crop residues that were retained or incorporated into the soils decreased the bulk density and compaction of the soils (Bellakki et al., 1998). The annual approach (Christian and Bacon, 1991; Ball et al., 1990)three years of applying 16 t ha^{-1} of rice straw reducedDepending on the cultivation techniques used, crop leftovers may be fully or partially absorbed into the soil (Dormaar and Carefoot 1996). It is more challenging to include rice leftovers before wheat planting than wheat straw because of the short time between rice harvest and wheat planting and the low temperatures that accompany them. However, some nutrients (nitrogen, for example) are temporarily immobilized when crop residues are added to the field, so additional nitrogenous fertilizer is needed to compensate for the high C:N ratio at the time of residue incorporation (Singh et al. 2005, Singh et al. 2008). Decomposer microorganisms are to blame for this temporary nitrogen deficiency because they immobilize the nitrogen found in soil and fertilizer. This time relies on the bulk density of decomposition, which ranges from 1.20 to 0.98 g cm^{-3} in the top 0–5 cm of a sandy loam. Lower infiltration results from increased compaction and decreased pore percentage of the surface soil caused by aggregate disintegration and surface seal formation from raindrop impact. Surface residue retention is used to alleviate this problem. Crop residue integration increased soil fertility, water holding capacity, microbial population, and infiltration rate while decreased BD compared to a no-residue treatment. Singh et al. (2010) found that integrating residue with NPK fertilizer led to the maximum yields, nitrogen uptake, residual soil fertility, and health of soil microorganisms..

2. **Impact on the biological health of the soil**

N, P, and S are especially reliant on soil microbial biomass (SMB) and microbial activity, both of which are dependent on the presence of organic substrates in the soil. Soil fauna and flora populations tend to increase in tandem with soil phyto-biomass levels. Soil treated with agricultural wastes had 1.5-11 times more fungus and 5-10 times more aerobic bacteria than soil that had been burned or removed, as observed by Sindu et al. (1995) and Beri et al. (1992). Soil microbial biomass (C and N) decreased with decreasing amount of residue kept on the soil surface, according to research by Verhulst et al. (2009) [40] conducted in the zero till treatments of both rainfed and irrigated long-term trials. Soil microbe biomass is directly related to the soil's ability to physically stabilize aggregates, as these organisms play a key role in the soil's cycling of nutrients (C, N, P, and S) and organic matter. The capacity of symbiotic bacteria to fix nitrogen in the soil is enhanced by crop wastes. An increase in soil microorganisms also increases the activity of soil enzymes that convert inaccessible forms of nutrients into usable forms.

3. **Impact on the chemical health of the soil**

The amount of crop residues integrated into the soil has a significant impact on the pH of the soil, which determines soil fertility. Applying straw to the soil over time will raise its organic matter content, boost its nitrogen stores, and improve its macro- and micronutrient availability. During the course of an 11-year field study on loamy sand soil, Beri et al. (1995) observed that adding crop residues to the rice-wheat system enhanced the total P and K content of the soil in comparison to removing the residues. According to a three-year study by Gupta et al. (2007), adding crop waste atop burned straw increased P release, decreased P sorption, and increased inorganic and organic P content. Through integrated residue, 50–80% of the micronutrients (Zn, Fe, Cu, and Mn) absorbed by rice and wheat crops can be recycled. Micronutrient availability in rice, including zinc and iron, is influenced by crop residue (Singh et al. 2005 and Gupta et al. 2007).The breakdown of residues is influenced by crop management, soil conditions, and residue properties. N immobilization can endure for four to six weeks in ideal temperature and moisture conditions. Soil microbial biomass (SMB) is affected by the strategies employed to manage residues. Many personnel have seen a reduction in microbial biomass after trash have been burnt. Assimilation of residues, as opposed to removal or burning, boosts microbial activity.

Conclusion

The nation's most intensive farming system is the rice-wheat combination. It makes up a disproportionately large portion of India's overall arable land. Its remains can be recycled with enormous potential to replenish the soil with a significant amount of plant nutrients. A significant concern to this system is the yield standstill that results from the decreasing soil organic carbon. Therefore, managing rice wastes effectively and efficiently is a major problem for farmers in order to improve carbon sequestration and preserve the sustainability of production. There are benefits and drawbacks to every managerial choice. A specific set of soil, climate, and crop management requirements must be met in order for it to be feasible, compatible with the machinery now in use, and socially and economically acceptable. If we want to stop residues from being burned in the rice-wheat cropping system, we need to study and improve the technology with mechanical harvesters. Conservation tillage methods can be modified to work with various soil types and climates. Research also indicates that a rice-wheat crop rotation is essential. The productivity of the rice-wheat cropping system can be maintained through careful management of rice leftovers, which will improve the soil's physical, chemical, and biological properties.

References

1. Lal R. Conservation tillage for sustainable agriculture:tropicsversustemperateenvironments.Adv.Agron.1989;42:85-197.
2. MoA.(MinistryofAgriculture).Govt.ofIndia,NewDelhi.2012.www.eands.dacnet.nic.in.
3. JanaiahA,HossainM.Farm-levelsustainabilityofintensive rice–wheat system: socio-economic and policyperspectives. Addressing Resource Conservation IssuesinRice–WheatSystemsofSouthAsia,AResourceBook,RiceWheatConsortiumforIndoGangeticPlains(CIMMYT),2003.
4. Dobermann A, Fairhurst TH. Rice Straw Management.BetterCropsInternational,Specialsupplementpublication:RiceProduction.2002,16.
5. GaddeB,MenkeC,WassmanR.RicestrawasarenewableenergysourceinIndia,ThailandandthePhilippines: Overall potential and limitations for energycontribution and greenhouse gas migration. Biomass andBioenergy.2009;33:11.
6. MNRE.(MinistryofNewandRenewableEnergyResources)Govt.ofIndia,NewDelhi.2009.www.mnre.gov.in/biomassrsources
7. SarkarA,YadavRL,GangwarB,BhatiaPC.CropresiduesinIndia.Tech.Bull.,ProjectDirectorateforCroppingSystemResearch,Modipuram,1999.
8. SinghY,SinghB.EfficientManagementofPrimaryNutrientsintheRice-WheatSystem.In: Kataki, P.K.(Ed.). The Rice-Wheat Cropping Systems of South Asia:Efficient Production Management. Food Products Press,NewYork,USA.2001,23-85.
9. Gupta RK, Shukla AK, Ashraf M, Ahmed ZU, SinhaRKP, Hobbs PR. Options for establishment of rice andissues constraining its productivity and sustainability ineastern Gangetic plains of Bihar, Nepal and Bangladesh.Rice-WheatConsortiumTravellingSeminarReportSeries 4. New Delhi, India: Rice-Wheat Consortium fortheIndo-GangeticPlains.2002,36.

10. RaisonRJ.Modificationofthesoilenvironmentbyvegetationfires,withparticularreferencetonitrogentransformation:areview.PlantSoil.1979;51:73-108.
11. Ponnamperuma FN. Straw as a source of nutrients forwet-land rice. In: Banta, S. and Mendoza, CV (Eds.).Organic Matter and Rice. IRRI, Los Banos, Philippines,1984,117-136.
12. Lefroy RDB, Chaitep W, Blair GJ. Release of sulphurfromriceresidueunderfloodedandnonfloodedsoilconditions.Aust.J.Agric.Res.1994;45:657-667.
13. Sarwar M, Khan MA, Nisa M. Effect of organic acids offermentable carbohydrates on digestibility and nitrogenutilization of urea treated wheat straw in buffalo bulls.Australian Journal of Agricultural Research. 2004; 55:223- 228.
14. SidhuBS,BeriV.Experiencewithmanagingriceresiduein intensive rice-wheat cropping system in Punjab. In:ConservationAgriculture-StatusandProspects(EdsAbrol IP, Gupta RK and Malik RK) CASA, New Delhi.2005,55-63.
15. CrisanEV,SandsA.Nutritivevalueofediblemushrooms. In Chang ST Hayes WA, eds. The Biologyand Cultivation of Edible Mushrooms. Academic Press.NewYork.1978,137-168.
16. WuestPJ,RoseDJ,BeelmanRB.CultivatingEdibleFungi.Elsevier,Amsterdam,1987.
17. MaherMJ.ScienceandCultivationofEdibleFungi.Rotterdam(TheNetherlands):AABalkema.Ed,1991.
18. LemannJ,JosephS.Biocharforenvironmentalmanagement:anintroduction.InBiocharforenvironmentalmanagement:ScienceandTechnology.LemannJandJosephS(Eds).Earthscan,London,2009.
19. Spokas KA, Koskinen WC, Baker JM, ReicoskyDC.Impactsofwoodchipbiocharadditionsongreenhousegasproductionandsorption/degradationoftwoherbicidesinMinnesotasoil.Chemosphere.2009;77:574-581.
20. Zhang A, Bian R, Pan G, Cui L, Hussain Q, Li L *et al*.Effects of biochar amendment on soil quality crop yieldand greenhouse gas emission in a Chinese rice paddy: Afield study of 2 consecutive rice growing cycles. FieldCropRes.2012;127:153-160.
21. JeongCY,DodlaSK,WangJJ.Fundamentalandmolecularcompositioncharacteristicsofbiocharproduced from sugarcane and rice crop residues and by-products. Chemosphere 2015. http://dx.doi.org/10.1016/j.chemosphere.2015.05.084.
22. BallBC,RobertsonEAG.Strawincorporationandtillagemethods:Strawdecomposition,denitrificationand growth and yield of wheat. J. Agric. Eng. Res. 1990;46:223-243.
23. Christian DG, Bacon ETG. The effect of straw disposaland depth of cultivation on the growth, nutrient uptakeand yield of winter wheat on clay and a silt soil. Soil UseManage.1991;**7**:217-222.
24. Dormaar JF, Carefoot JM. Implications of crop residuemanagementandconservationtillageonsoilorganicmatter.Can.J.PlantSci.1996;76:627-63.

25. Singh Y, Singh B, Timsina J. Crop residue managementfor nutrient cycling and improving soil productivity inrice-based cropping systems in the tropics. Adv Agron,2005;85:269-407.
26. SinghB,ShanYH,Johnson-beeeboutSE,SinghY,Buresh RJ. Crop residue management for lowland rice-basedcroppingsystemsinAsia.AdvAgron,2008;98:118-199.
27. Singh B, Bronson KF, Singh Y, Khera TS, Pasuquin E.Nitrogen15balanceanduseefficiencyasaffectedbyriceresiduesmanagementinaricewheatsystemofnorthwestIndia.Nut.Cycl.Agroecosyst.2001;59:227-237.
28. SinghY,SinghB,LadhaJK, Khind,CS,KheraTS,Bueno CS. management effect on residue decomposition,crop production and soil fertility in rice wheat rotation inIndia.SoilSci.Soc.Am.J.2004;68:320-326.
29. ErensteinO,LaxmiV.Zero-tillageimpactsinIndia'srice wheat systems: a review. Soil and Tillage Research.2008;100(1-2):1-14.
30. Ladha JK, Kumar V, Alam MM, Sharma S, Gathala M,ChandanaP*etal.*Integratingcropandresourcemanagementtechnologiesforenhancedproductivity,profitability, and sustainability of the rice-wheat systeminSouthAsia.In:IntegratedCropandResourceManagement in the Rice-Wheat System of South Asia(Eds: Ladha J K, Singh Y, Erenstein O and Hardy B)InternationalRiceResearchInstitute,LosBanos,Philippines.2009,69-108.
31. Sidhu HS, Singh M, Humphreys E, Singh Y, Singh B,DhillonSS*etal.*TheHappySeederenablesdirectdrilling ofwheatintoricestubble.AusJExpAgric.2007;47:844-854.
32. Chakraborty D, Garg RN, Tomar RK, Singh R, SharmaSK, Singh RK *et al.* Synthetic and organic mulching andnitrogen effect on winter wheat (*Triticum aestivum*L.) inasemi-aridenvironment.AgricWaterManage.2010;97:738-748.
33. Chakraborty D, Nagarajan S, Aggarwal P, Gupta VK,Tomar RK, Garg RN *et al.* N Effect of mulching on soiland plant water status, and the growth and yield of wheat(*Triticum aestivum*L.) in a semi-arid environment. AgricWaterManage.2008;95:1323-1334.
34. Beri V, Sidhu BS, Bhat AK, Singh BP. Nutrient balanceand soil properties as affected by management of cropresidues. In: Proceedings of the international symposiumonnutrientmanagementforsustainedproductivity.DepartmentofSoils,PunjabAgriculturalUniversity,Ludhiana, Punjab, India. (Ed: Bajwa M S). 1992; II:133-135.
35. BeriV,SidhuBS, BahlGS, BhatAK.Nitrogenandphosphorus transformations as affected by crop residuemanagement practices and their influence on crop yield.SoilUseManage.1995;11:51-54.

36. SinghG,JalotaSK,SidhuBS.Soilphysicalandhydraulic properties in a rice-wheat cropping system inIndia:effectsofrice-strawmanagement.SoilUseManage.2005;21:17-21.
37. BellakkiMA,BadanurVP,SettyRA.Effectoflong-termintegratednutrientmanagementonsomeimportantproperties of a Vertisol. J. Indian Soc. Soil Sci. 1998;46:176-180.
38. Singh SK, Kumar D, and Lal SS. Integrated use of cropresiduesandfertilizersforsustainabilityofpotato(*Solanum tuberosum*) based cropping systems in Bihar.IndianJAgronomy.2010;55(3):203-208.
39. Sindu BS, Beri V, Gosal SK. Soil microbial health asaffectedbycropresiduemanagement.In:Proc.Natl.Symp. On developments in soil science Ludhiana. IndianSocietyofSoilScienceNewDelhi.1995;2-5:45-46.
40. Verhulst N, Sayre KD, Vargas M, Crossa J, Deckers J,RaesD.Wheatyieldandtillage-strawmanagementsystemxyearinteractionexplainedbyclimaticco-variablesforanirrigatedbedplantingsysteminnorthwestern Mexico. Field Crops Res. 2011; 124:347-356.
41. Gupta RK, Singh Y, Ladha JK, Singh B, Singh J, SinghG *et al*. Yield and phosphorus transformations in a rice-wheatsystemwithcropresidueandphosphorusmanagement. J American Soc Soil Sci. 2007; 71:1500-07.