Plant Archives Vol. 24, No. 2, 2024 pp. 1457-1466 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2024.v24.no.2.204

OPTIMIZING RICE STRAW UTILIZATION FOR SOIL ENHANCEMENT: A STRATEGIC APPROACH TO RICE STRAW MANAGEMENT AND ITS IMPACT ON SOIL PROPERTIES

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(Date of Receiving-23-01-2024; Date of Acceptance-31-03-2024)

ABSTRACT

Rice straw, an easily accessible organic by product derived from rice cultivation, possesses a multitude of uses. It recycles nutrients and improves soil quality, making it an effective rice straw management alternative. The integration of recently harvested rice residue into rice fields promotes the recycling of nutrients and improves soil quality. Rice straw is used in mushroom cultivation, livestock feed, and other industries and homes. Soil quality improves with rice straw because it cycles nutrients and sequesters organic carbon. This increases moisture retention, nutrition, and highland rice production. When compared to bare soil, crop residue reduces runoff water by over 90%. Additionally, it enhances aggregation, water sorptivity, density, porosity, and porosity of the soil. Sustainable agriculture is promoted by the incorporation of rice straw into the soil, which results in increased crop yields, improved soil fertility, and the conservation of ecosystem services.

***Key words*:** Crop residue, crop productivity, rice straw, soil properties

Introduction

Rice is a crucial staple crop in various regions globally and plays a fundamental role in ensuring global food security. Straw is a by-product of rice grain production and has various uses, including thatching, animal feed, and manure. In the Indian context, the average production of paddy straw is 126 metric tonnes (Singh *et al.*, 2016). Due to limited rice-straw utilisation options, farmers must burn straw in the fields. Rice straw accounts for 60% of India's 16% field burn (Bhattacharyya *et al.*, 2020). Air quality has plummeted due to the startling rise in open field straw burning, resulting in heightened emissions of detrimental gases such as carbon monoxide (CO), nitrogen oxides (NOx), sulphur dioxides (SO_2), volatile organic compounds (VOC), and cancer-causing polycyclic aromatic hydrocarbons (PAH) (Oanh *et al.*, 2011). The contribution of the rice cultivation to the emission of the greenhouse gases is very alarming. Straw-burning in the country results in significant nutrient losses, including nitrogen (~40%), potassium (~33%), and sulphur (~45%) (Dobermann and Fairhurst, 2002; Bhattacharyya *et al.*, 2020). Hence, the environmental friendly alternative of rice straw management is necessary.

In light of the aforementioned finding, the review's goal has been to present comprehensive and current data regarding the drawbacks of the conventional approach to managing straw, as well as its constituent parts, current and developing tactics, their effects on soil health and conservation, prospects, and future focus areas.

Harmful effects of traditional methods of rice straw management

Rice straw management in India, following the conventional method, has a substantial ecological footprint. Farmers employ both conventional and mechanised agricultural techniques as a result of a shortage of labour.

Nevertheless, the combustion of rice straw emits noxious gases and particulate matter into the atmosphere (Pushpa and Sinha, 2011). Burning paddy straw in open fields releases CO_2, contributing to the greenhouse effect and harming local respiratory health. (Zayed & Abdel-Motaal 2005). Farmers often burn rice straw residue due to time constraints, as it is a fast and cost-effective method (Chandra *et al*., 2017, Yadav *et al*., 2015). Nutrients are lost from rice straw, requiring more fertilizer and adding financial strain on farmers. Finding cost-effective solutions for paddy straw burning is crucial (McLaughlin *et al*., 2016). Rice-growing areas need machines to incorporate straw into the soil. Burning straw reduces soil fertility and organic carbon. Incinerating rice straw affects soil quality depending on fire intensity, duration, moisture, tillage, time gap, and features. Ponnamperuma (1984) emphasised the importance of considering the period of straw burning when assessing its sustainability, as the impact on soil fertility gradually increases over time. However, research suggests that the disadvantages of burning, such as nutrient loss, depletion of soil organic carbon, and reduction in beneficial soil biota, outweigh the advantages (Mandal *et al*., 2004). Rice consumes approximately 80% of its potassium from straw, hence straw management is important for potassium recycling. Thus, rice straw removal from field can deplete soil potassium. Seyfferth *et al*., (2013) and Wickramasinghe and Rowell (2006) found that straw management affects soil silicon interactions. In South Asia, rice straw removal causes potassium and silicon shortages, lowering rice output. This process depletes soil organic carbon, harming the ecology. Lower carbon biomass, nitrogen cycling, and soil organism food and energy supply decrease. The above variables degrade soil quality (Vijayaprabhaka *et al*., 2017).

Estimates of crop residue and rice-straw generation in India

Crop residue is the rice leaves, stem, and roots following economic section removal after other uses. The rice stem is straw, while the stubble remains in the soil after harvesting. Chaff is empty grains and husk is the leftover component after milling. Between the years 1994 and 2015, quantified rice crop residue generation in India showed a large range of variability (Agarwal, 2007; NAAS, 2012; Government of India, 2014; Jain *et al*., 2014 and Devi *et al*., 2017). The range of the data was from 122 to 341 MT. However, the latest rice-straw generation estimations showed that residue generation has increased with annual rice grain output changes. In addition, the state of West Bengal produces the most straw (17.38 MT) among all of India's states, followed by the state of Uttar Pradesh (20.63 MT) and Punjab (17.38 MT) India's three crop seasons, varying soils, and range of agricultural crops produce different crop wastes at different periods. Seasonality research shows that most agricultural wastes are accessible October–December, after *Kharif* (wet) season.

Table 1: Estimates of biomass generated from rice at different periods in India (P. Bhattacharya *et al*., 2021).

S. no	Biomass generated in million tonnes	Estimation for the year
	Rice	
1.	257.07 (grain + straw)	1994
2.	198.18 (straw)	2008-09
3.	341.41 (grain + straw)	2010
4.	192.82 (straw)	-
5.	122.6 (straw)	2014-15

Exploring the Various Components of Rice Straw

Rice straw and rice grain comprise rice harvest biomass. Milled paddy grain, bran, and husks are separated. Because it is harvested, rice straw is moister than husks and bran, which are drier after grinding dried paddy. Threshing separates grains from straw, leaving stalk and stubble. Cutting height determines stubble. Brown rice requires husk removal while white rice requires bran removal. Processing can use other rice plant parts for composting, biofuel generation, or other uses.

Existing and emerging rice straw residue management options

After rice stubble burning, farmers use burned ash on soil differently because straw burning was banned. With fresh rice residue, they can recycle nutrients and enhance soil quality, but it may produce greenhouse gases. Mix straw with other materials to generate high-quality compost with earthworms and microbes. While mushroom straw can be used for compost and vermicompost, growers normally save it for lucrative crops. Straw can be used to generate electricity and carbonised rice straw can modify soil (Haefele *et al*., 2011). The following is a list of several management choices for paddy straw management, varying in terms of their relative viability and appeal:

Mulch

The use of paddy straw as mulch in zero-tillage production is crucial. In traditional rice production, straw is temporarily removed from the field and returned as mulch after puddling (Goswami *et al*., 2020). The increase in water use efficiency, crop output, and soil organic carbon decreases soil temperature, bulk density, and weed

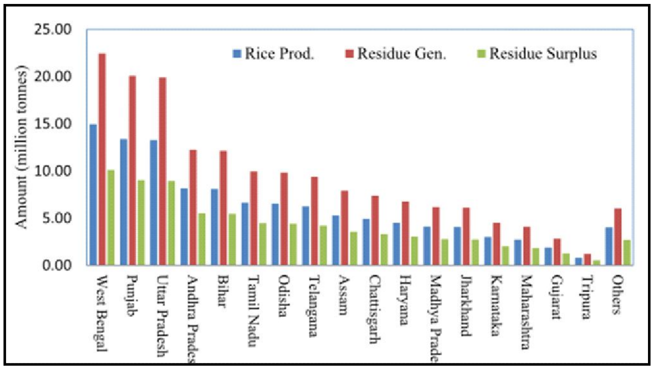

Fig. 1: State-specific residue and surplus (during 2017-18) (Bhattacharya *et al.*, 2021).

dry matter (Ram *et al.*, 2013). Mulching is used to keep the soil moist and keep birds from harvesting the seeds. Mulching insulates vegetables from winter frost. Straw residue improves soil fertility and nutrition. Straw is cheap, accessible, and biodegradable, making it cheap mulch for farmers. Mulching retains soil moisture and boosts rapeseed germination. (Bidyalukshmi *et al.*, 2023). Rice waste from the field can be utilised as mulch to boost vegetable crop productivity (Vos *et al.*, 1995). Transportation and labour expenses, farmer profits, and rice residue uses determine this management option's profitability. Rice straw's neutral pH and low weight make it suitable for mulching to control weeds and keep soil moisture, decreasing water and weedicide use. According to Rahman *et al.*, (2005), rice straw mulching in the field can be easily integrated into the soil after the crop and utilised to cover plants in winter to protect them from harsh cold. Rice straw mulching was studied for wheat crop growth. Mulching grew wheat roots, retained water, and controlled weeds.

Soil incorporation

Straw may be incorporated into the soil through the utilisation of a cultivator or a disc. Harvest process and straw height determine stubble amount. In rice-rice cropping systems with a 2-3 month gap between crops, cut the rice residue into 20-25cm lengths and immediately incorporate it into the soil after harvest for best results. This speeds decomposition and nutrient release. Rapid shallow incorporation breakdown loses 50% residue-C in 30-40 days enhanced plant nitrogen availability. Implementation immediately after harvest boosts rice transplanting soil ammonium and nitrogen uptake. Rice residue shallow integration reduces phenol degradation, soil cracking, and weeds in aerobic conditions. Effective soil management requires timing residue incorporation. Soil is amended with rice straw from crop gaps. Combine harvesters yield. Monocropping systems shallowly incorporate rice straw to accelerate decomposition and nutrient uptake (Goswami *et al.*, 2020). Wetting, drying, and rice straw incorporation reduce gas emissions, increase water productivity, and boost Southeast Asian crop yield. Straw and stubble replenish soil nutrients. When comparing straw removal, consider short-term grain yield. Early, shallow 5-10 cm tillage within 2-3 weeks of harvest improves rice-rice soil fertility. Systems with a 30-day dry-moist fallow period benefit from this (Dobberman and Fairhurts, 2002).

Benefits of soil incorporation of straw:

(a) Increase M mineralization and soil P release to the next crop until panicle initiation, and reduce weed growth.

(b) By reducing soil cracking and water losses in heavy clay soils, crop residue decomposition improves rice growth and water demand during land preparation. Within 30-40 days, it contributes 50% of carbon turnover.

Ruminant Feed

For years, rice straw has fed cattle. Straw is frequently fed to cattle in Africa and India. Despite varied outcomes, it's a major feed component despite low nutritional value (Drake *et al.*, 2002). Ruminants have trouble digesting rice straw, which has little protein. Rice straw can be eaten by animals at 2% body weight daily. A report says ruminants eat 1.2 kg of straw (dry matter) per 100 kg of live weight daily. It's important to recognise animal eating differences. Sodium hydroxide, urea, ammonia, or lime increase rice straw taste and digestibility. These compounds destroy straw's alkaline- or acidic-sensitive lignin-cellulose connections (Gummert *et al.*, 2020).

Composite materials

Combine agricultural bio-wastes with metals and polymers to make sustainable composites. The eco-friendly and commercial green composites have several uses. With adhesives, rice straw and husk produce particle

Table 2: The elemental composition of unprocessed rice straw (Viji and Neelanarayanan, 2015).

S. no.	Parameters	%
1.	Cellulose	36.83±0.75
2.	Hemicellulose	23.83±1.47
3.	Lignin	151.26
4.	Organic carbon	42.53±0.19
5.	Total nitrogen	0.5±0.004
6.	Total phosphorus	0.02±0.004
7.	Total potassium	0.76±0.04
8.	C:N ratio	85:1

boards. In a study conducted by Pan *et al*., (2006), rice straw particle boards were fabricated using polymeric methylene diphenyl diisocyanate (PMDI) as a binder. Rice bran adhesive was combined with PMDI despite its disadvantages to achieve comparable binding outcomes. Rice straw is combined with PVC/PP to form composite materials. Rice straw treatment affects composite properties. Ceramics and metals work with rice straw. Aluminum-based MMCs (metal matrix composites) are stronger, harder, and wear-resistant with rice straw ash. Thermal expansion coefficient differences create strain fields around ash particles. Rice straw-green metal matrix composites need more research due to limited studies.

Use as substrate in mushroom cultivation:

Rice straw is the most common substrate for mushroom growth. With scientific intervention, mushroom production is being done on a large scale, using paddy straw as a substrate, resulting in rice straw being widely used rather than discarded. Mushroom cultivation by farmers using field straw has allowed them to double their income. Despite the current prevalence of mushroom cultivation, the gathering of abundant straw mushrooms (*Volvariella* sp.) has been a tradition passed down from generation to generation. From April to July, the mushroom grows in rain-wet paddy straw heaps near the barn. This mushroom has been eaten since ancient times. (Bidyalukshmi *et al*., 2023).

Impact of rice straw management on soil health

Nutrient cycling

The incorporation of rice straw into soil has been found to have a positive impact on soil quality by promoting nutrient cycling and sequestering soil organic carbon. Several studies have shown that straw incorporation enhances nutrient recycling and provides fertility benefits to the soil (Dobermann and Fairhurst, 2000). Rice straw is an abundant organic material available to most rice farmers and is a significant source of potassium (K). Research conducted by Ponnamperuma in 1984 revealed that rice straw has 0.57% N, 0.07% P_2O_5, 1.5% K_2O, 0.1% S, and 5% Si. Rice straw boosted soil pH, organic carbon, and nutrients, according to Thanh *et al.* (2016). Straw has little nitrogen, yet huge amounts are needed to supply nitrogen. Straw must decompose to release nutrients for plant uptake, and the rate depends on soil type and season. Moreover, during the application season, only a fraction of the nutrients present in straw become accessible (Thuy *et al*., 2008). Rice straw of inferior quality has a high C:N ratio, which retards nitrogen decomposition. Higher C:N ratios indicate lower quality and slower breakdown, while lower ratios indicate higher quality and faster breakdown. Utilising rice straw as a post-crop amendment enhances nitrogen availability. Rice straw also provides sulphur and zinc, especially when used with sulphur-deficient fertilisers (Eagle *et al*., 2000). Zinc availability may decrease with long-term rice straw use (Yadvinder-Singh *et al*., 2005).

Table 3: The nutritional content of rice straw and the nutrients recovered from 1 tonne of straw residue.

Parameters	N	P	K_2O	S	Si
Straw dry matter %	0.5-0.8	0.16-0.27	1.4-2.0	0.05-0.10	4-7
Removal with 1 tonne straw, Kg/ha	5-8	1.6-2.7	14-20	0.5-1.0	40-70

Effect on yield

The practice of retaining crop residues in cropping systems is lead to increased yields. Incorporating rice straw 20 days before sowing wheat without N fertilisation decreased wheat production but enhanced rice yield after wheat. Adding rice straw boosted wheat yield by 28% (Zhang *et al.*, 2015). In South Asia, rice straw removal causes K and Si deficits that impair rice output (Wickramasinghe and Rowell, 2006). Rice straw removal from the field degrades soil quality by reducing soil organic C, carbon biomass, nutrient cycling, and food/energy availability for soil organisms (Vijayaprabhaka *et al.*, 2017). Due to the improved soil temperature and moisture content, rice straw mulching increased plant height, longest root length, and overall root development. Particularly in the early stages of the rice crop, this fostered an environment that was conducive to robust plant development (Devi Dayal *et al*., 1991). Devasinghe *et al*., (2013) suggest that the increase in yield could be attributed to the suppression of weeds during the critical period of weed competition, which lasts for the first 30 to 45 days. In India, adding rice straw to soil increased wheat grain yield by 13% compared to removing it. Straw increased grain yields, especially when combined with diverse cropping systems, tillage, and crop establishment (Nandan *et al*., 2018). Rice yield increased from 3.0% to 8.2%, although maize and wheat yields increased more due to moisture conservation in highland settings and nutritional contribution from straw (Chivenge *et al*., 2020).

Control of soil erosion and land degradation:

Crop residue protects against raindrop-induced forces and increases surface roughness, reducing runoff water by over 90% compared to bare soils. This reduces soil erosion and nutrient loss by increasing water infiltration and decreasing runoff. Several studies show crop residue reduces runoff and erosion. Cerda *et al*., (2016) and Prosdocimi *et al*., (2016) found that agricultural residue cover reduces runoff water. Park *et al.*, (2018) and Shin *et al.*, (2013) both noted that crop residue reduces soil erosion and nutrient loss. Runoff is reduced by land slope, according to Scopel *et al*., (2005). Steeper slopes tend to lead to more significant reductions in runoff. Crop residue cover reduces runoff less with higher rainfall, suggesting that rainfall intensity affects infiltration and surface flow rate. Crop residue cover also prevents raindrop-induced soil erosion, preserves soil structure and fertility, and boosts crop development and production. Blanco-Canqui and Lal, (2009) and Ranaivoson *et al.*, (2017) underlined the relevance of crop residue cover in decreasing soil and nutrient losses from sloping highland fields and encouraging crop growth. Crop residue cover protects against raindrops, slows water flow, and improves infiltration, reducing runoff, erosion, and nutrient loss. Conservation and sustainability are supported by improved crop soil conditions. Rice straw is ideal for covering and replanting. Storm water and sediment can be managed with straw bales in erosion-prone locations, according to ICAR (Bhattacharya *et al*., 2021). Won *et al*., (2016) tested rice straw with polyacrylamide (PAM) and gypsum as mulch on a Chinese cabbage plot in South Korea. Even on a higher slope, the total runoff ratio reduced 29.4% from the control plot. A sloping agriculture field was used to create three treatment plots by Choi *et al.*, (2016) in South Korea. Straw mat mulch, gypsum, and PAM were used. The straw mat mulch, gypsum, and PAM plot reduced runoff most. Another study by Ahn and Kim, (2016) evaluated mulching on sandy loam soil in South Korean upland crops. For radish and sesame cultivation on slopes of 3% and 8%, rice-straw mulching reduced runoff ratio and sediment loss by 9% and 95.9%, respectively.

Impact on soil properties:

Porosity, bulk density, water sorptivity, and aggregation affect soil water infiltration. Surface residue improves infiltration and reduces evaporation, making soil water retention better. In prolonged dry periods, residue cover may not be better than bare soil. Crop residues improve soil structure, root development, and plant growth by adding organic matter. Understanding the impact of residue management on soil properties and crop productivity is crucial.

Table 4: Cropestablishment method affects rice yield components (Devasinghe *et al.*, 2013).

Yield components of rice				
Method of crop establishment	**Panicle no./m²**	**Spikelet per panicle**	***FG**	**TGW (1000)**
*WDSR-UW	185.2	78.2	85.9	21.3
*WDSR-RSM	327.6	100.4	88.4	21.5

*FG= Filled Grain, TGW= Thousand grain weight, WDSR = Wet direct seeded rice, UW= unweeded, RSM= Rice straw management

Table 5: Crop establishment method affects rice plant height (cm) (Devasinghe *et al*., 2013).

Plant Height (cm)					
Method of crop establishment	**14 DAS***	**28 DAS**	**35 DAS**	**PI**	**50% H**
WDSR-UW	5.2	8.9	11.8	17.6	42.4
WDSR-RSM	6.4	11.4	14.0	21.7	53.8

*DAS= Days after sowing, PI= Panicle initiation, H=Heading

Soil organic carbon

Soil organic matter (SOM) is the substance produced by living organisms and then returned to the soil for decomposition. One of the key roles of SOM is that it serves as a source of essential nutrients for plants and also acts as water absorbent. Yadvinder-Singh *et al*., (2004) found that integrating rice residue for 7 years before growing wheat increased soil organic carbon from 0.41 to 0.59 g kg^{-1}. Organic carbon content increased more in sandy loams than silt loams, especially when the initial organic carbon content was smaller (Yadvinder-Singh *et al*., 2009). This highlights the importance of SOM in improving soil quality and fertility.

Aggregation and soil structure

Soil aggregation is influenced by various factors, including parent material, climate, vegetation, and management approaches. Crop residues improve soil aggregation and stability via influencing soil strength, porosity, hydraulic characteristics, air diffusion capacity, and soil aggregates. Organic carbon quantity alone does not determine soil structure improvement; organic matter composition and management system also contribute.

Table 6: Crop establishment method affects shoot dry weight (g/m^2) of rice (Devasinghe *et al*., 2013).

Shoot Dry Weight (g/m^2)					
Method of crop establishment	**28 DAS**	**35 DAS**	**PI**	**50% H**	**Harv.**
WDSR-UW	44.8	85.7	191.2	286.5	608.1
WDSR-RSM	94.1	95.7	322.2	621.9	987.5

*DAS= Days after sowing, PI= Panicle initiation, H=Heading

Table 7: Crop establishment method affects root dry weight (g/m^2) of rice (Devasinghe *et al*., 2013).

Root Dry Weight (g/m^2)					
Method of crop establishment	**28 DAS**	**35 DAS**	**PI**	**50% H**	**Harv.**
WDSR-UW	44.8	85.7	191.2	286.5	608.1
WDSR-RSM	94.1	95.7	322.2	621.9	987.5
*DAS= Days after sowing, PI= Panicle initiation, H=Heading					

Table 8: Crop establishment method affects length of the longest root (cm) of rice (Devasinghe *et al*., 2013).

Length of the Longest Root (cm)					
Method of crop establishment	**14 DAS***	**28 DAS**	**35 DAS**	**PI**	**50% H**
WDSR-UW	7.4	7.4	11.6	16.0	13.2
WDSR-RSM	8.5	8.5	14.6	15.5	15.2
*DAS= Days after sowing, PI= Panicle initiation, H=Heading					

Saturated hydraulic conductivity (Ks)

Water movement in soil is influenced by porosity. Increasing porosity improves water movement, while the presence or absence of crop residues affects hydraulic conductivity. Removing residues can decrease hydraulic conductivity. A study conducted by Tripathi *et al*., (2007) found that the removal of crop residues resulted in a decrease in saturated hydraulic conductivity across all tillage systems. This highlights the importance of managing crop residues to maintain optimal soil hydraulic conductivity.

Infiltration rate (IR)

Mulched soils tend to retain more moisture during the spring and summer months than unmulched soils (Shaver *et al*., 2002). Mulching promotes soil moisture, reduces weeds, and boosts soil production. Different agricultural leftovers have an impact on soil moisture, temperature, weeds, salinity, nutrients, and physical qualities, all of which affect crop output. Research showed that mulched soils retain 20-50% more water than unmulched soils within a water potential range of 0 to -6 k Pa (Blanco-Canqui *et al*., 2007).

Bulk density and compaction

The inclusion of crop residue into the top layer of soil has been found to have a positive impact on its bulk density. In 2003, Shaver *et al*. found that adding 1 tonne of crop residue per hectare for 12 years decreased bulk density by 0.01 Mg/m^3. Organic carbon increased 0-25 mm macro aggregates by 4.4%. Water absorption, soil infiltration, compaction, root growth, and nutrient absorption improve with no-till and crop residue. Adding crop residue to the soil has numerous benefits, such as improving soil health, increasing productivity, and enhancing water retention and infiltration.

Porosity

The addition of straw mulch cover at a rate of 0 to 12 Mg ha^{-1} resulted in an increase in macropores from 0.18 to 0.38 $mm^3\ mm^{-3}$ and mesopores from 0.07 to 0.08 $mm^3\ mm^{-3}$, whereas micropores decreased from 0.23 to 0.13 mm^3. Additionally, mulched soils contain a higher number of macropores, allowing for faster drainage than unmulched soils. Another study by Shaver *et al*., (2002) found that continuous cropping systems resulted in a larger increase in total porosity (0.54 $mm^3\ mm^{-3}$) than wheat-fallow systems (0.50 $mm^3\ mm^{-3}$) in a 12-year no-till system in the Great Plains region.

Soil temperature

Soil temperature is a crucial aspect of soil physics that has been extensively studied. In a study conducted

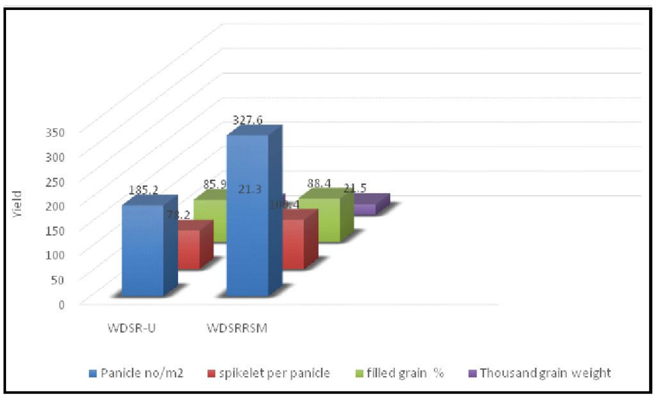

Fig. 2: Yield components of rice (panicle no./m^2, spikelet per panicle, filled grain, thousand grain weight) as affected by crop establishment (Devasinghe *et al*., 2013).

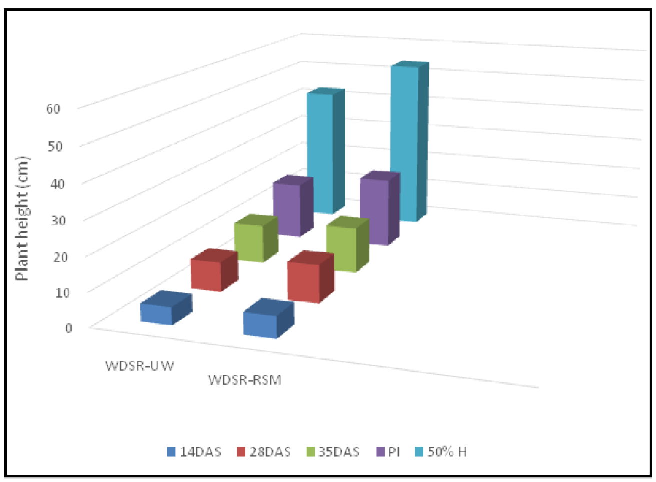

Fig. 3: Effect of rice crop residue on plant height (Devasinghe *et al*., 2013).

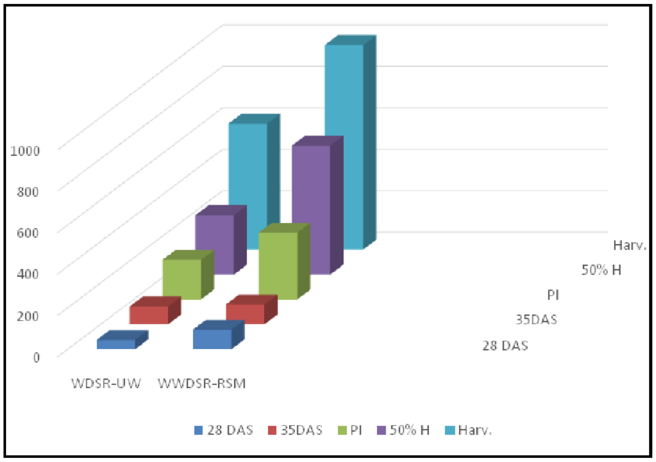

Fig. 4: Crop establishment affects rice shoot dry weight (g/ m^2). (Devasinghe *et al*., 2013).

by Prihar and Arora in 1980, it was found that the presence of straw mulch has a significant impact on soil temperature. In hot weather, straw mulch helps seed germination and plant growth, but in cold weather, it can hurt them. Its effect on soil temperature should be considered in agricultural decisions.

Effect on soil microbes

Soil microorganisms play a crucial role in the nutrient cycling process (Myrold, 1989). The presence of plant invaders can alter the soil-nitrifying microbial community, thereby affecting nitrogen cycling (Hawkes *et al*., 2005). Additionally, microorganisms have the ability to enhance the utilization of micronutrients by modifying their chemical properties (Rengel, 2001). Agricultural practices can influence the abundance and diversity of soil microorganisms. Short-term application of straw can lead to nitrogen immobilization by microbes and a decrease in nitrogen mineralization, resulting in increased net nitrogen retention (Garnier *et al*., 2003; Pan *et al*., 2017). Both short-term and long-term straw applications can benefit soil microorganisms, resulting in increased microbial biomass and activity (Fließbach *et al*., 2000; Enami *et al*., 2001). Incorporating rice straw into the soil has been found to boost the abundance of bacteria, fungus, and the overall microbial abundance (Zhang *et al*., 2018). The soil microbial community's functional diversity improves with increased microbial carbon metabolism, activity, and Shannons diversity index (Zhang *et al*., 2018). Greater soil microbial diversity is often associated with healthy soil (Tautges *et al*., 2016). As a result, the incorporation of rice straw has a beneficial impact on the diversity of soil microorganisms as well as the carbon metabolism of the soil.

Challenges in paddy straw management:

The introduction of photo insensitive short duration varieties of rice has significantly shortened the growing period of the crop. Farmers get a small window for the preparation of the field, hence they opt for rice straw burning (Kumar *et al*., 2015). Furthermore, the increased usage of harvesters causes the dispersion of rice residue in the fields, making it difficult to collect and handle further (Kumar *et al*., 2015). Due to government housing programs, the use of rice straw for thatching roofs has decreased (Bhattacharya *et al*., 2021). Over the years, unmanaged straw has significantly increased due to a disproportionate growth in production compared to the cattle population (Bhattacharya *et al*., 2021). The government's introduction of employment guarantee initiatives in rural areas, as well as rural migration, has exacerbated farmer suffering and straw burning (Bhattacharya *et al*., 2021). Employment guarantee schemes, such as the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), have lowered workforce availability, reducing the number of hands involved in rice straw management (DTE, 2015).

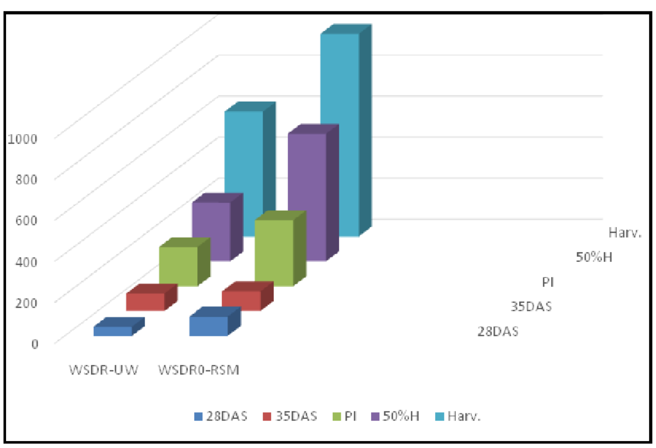

Fig. 5: Root dry weight (g/m^2) of rice as affected by crop establishment (Devasinghe *et al*., 2013).

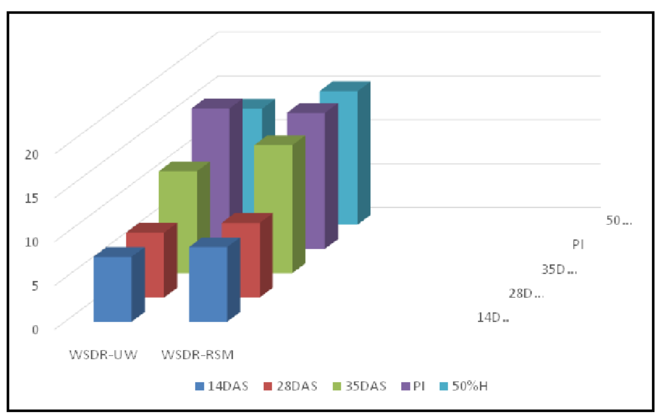

Fig. 6: Crop establishment affects rice longest root length (cm). (Devasinghe *et al*., 2013).

Prospects for the future

The usage of combine harvesters has increased the rice straw in fields, benefiting soil with higher yields, improved nutrient cycling, and organic matter accumulation. However, careful management of timing and water usage is crucial to minimize negative impacts like greenhouse gas emissions and phenolic compound release. To maximise benefits while minimising drawbacks, investigate alternative machinery options and determine the optimal straw quantity that does not interfere with land preparation or crop growth. It is important to investigate different methods of collecting straw, particularly with combine harvesters. Consider both the benefits and the drawbacks before deciding whether or not to collect straw. The incorporation of rice straw into agricultural fields should be given priority in order to advance sustainable agriculture, which will improve soil fertility, crop yields, and ecosystem services. Putting an emphasis on holistic benefits is an effective way to encourage sustainable approaches.

Conclusion

The management of rice straw disposal in India has escalated into a substantial concern, frequently resulting in fires sparked by farmers burning the straw to save time. Because farmers must prepare the field quickly for *Rabi* crop sowing after paddy harvest, stubble burning is popular. Based on the findings of this study, it has been observed that keeping paddy straw in the soil leads to enhanced physical and chemical properties. Additionally, it promotes the growth and activity of microorganisms, making it a more advantageous approach compared to burning the residues. It is crucial to promote the integration of paddy straw into the soil as a means to improve its physical, chemical, and biological properties, as opposed to the alternative method of burning it. In cropping systems that are based on rice, this strategy has the potential to significantly increase the amount of plant nutrients that are returned to the soil.

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