***Review Article***

# The effect of stubble burning and residue management on soil properties: A review


## Abstract

Stubble burning, a common agricultural practice, has gained significant attention due to its adverse effects on soil properties and environmental sustainability. The *in-situ* burning of stubble, especially in the context of the rice-wheat cropping system, can significantly alter the physical and chemical properties of soil, particularly in the topsoil layer. The factors contributing to crop residue burning in India include time constraints between successive crops which necessitates the need to clear fields quickly and limited access to mechanized equipment for residue management. As a result, many farmers resort to burning crop residues as a quick and cost-effective method to clear fields for the next planting season. *In situ* stubble management techniques offer sustainable alternatives to address these issues and promote soil health as this once-dismissed residue transforms into a strategic tool for nurturing soil vitality. This review paper provides a comprehensive analysis of the impact of stubble burning on various soil properties. It synthesizes existing literature and research findings to elucidate theinteractions between stubble burning and soil health and evaluates the long-term consequences of stubble burning on soil fertility and productivity.



**Keywords:**residue incorporation, rice-wheat cropping system, stubble burning, soil fertility


## Introduction

Stubble burning or crop residue burning refers to the practice of deliberately setting fire to agricultural residue left after harvesting crops such as rice, wheat and sugarcane. Stubble burning is typically done to clear the fields quickly and inexpensively, making them ready for the next planting season. It is a common agricultural practice that has been used for generations to clear fields after harvest. This practice is prevalent in several parts of the world, including India, Chinaand parts of Southeast Asia. Stubble burning is widely prevalent in India, with studies estimating that about 90% of farmers in Punjabburn their stubble in the field(Ravindra *et al*., 2018).The amount of stubble burnt varies depending on the crop. For rice, it is approximately 44 million tonnes per year, while for wheat, it is about 24 million tonnes per year (Thumaty *et al*., 2015). Overall, it is estimated that about 84 million tonnes of stubble are burnt in the field annually in India (Pratika and Sandhu, 2018).

The Rice-Wheat cropping sequence (RWCS) represents the largest agricultural production system globally, with approximately 12.3 million hectares in India. Nearly 85 percent of this cultivated area is situated in the Indo-Gangetic plains (IGP) region,extending from Punjab in the Northwest to West Bengal in the East, as noted byTimsina and Connor (2001).Crop residue burning is predominant in the agriculturally important states Punjab, Haryana, Uttar Pradesh and West Bengal. The need to adopt the rice-wheat cropping system by the farmers stems from the requirement to feed an ever-growing population, which was popularised by the Green Revolution but with that, also comes the issue of residue management.

Of the 620 million metric tons of crop residues generated yearly in the country, 234 million metric tons are surplus, with rice and wheat contributing 30% to it.Out of the total crop residue burned, rice and wheat contribute 62%, which accounts for approximately 16% of the total (Singh *et al*., 2020).Jain *et al.* (2014) reported that the production of cereal crop residues was highest in Uttar Pradesh followed by Punjab, West Bengal, Andhra Pradesh and Haryana. Uttar Pradesh was the leading contributor to sugarcane residue generationwhile Gujarat led in fibre crop residue production.In 2017-18, it was estimated that 334 million tons of crop residue were generated from cereals alone, the sources mainly being wheat straw, paddy straw, maize stalks and leaves and the highest contributor was rice which generated 145.5 million tons in the country (Venkatramanan *et al.*, 2021).Another study revealed that out of 141 million tons of crop residue surplus, 92 million tons was burned (Bimbraw, 2019).

Crop residue burning is a common practice in agriculture for several reasons.In the kharif season, rice (paddy) is cultivated between May and June and harvested in October or November. However, there exists a brief gap of approximately ten to fifteen days between rice harvest and the subsequent wheat sowing, which ideally occurs in November or early December. To prepare the land for wheat cultivation, farmers often resort to the most convenient and cost-effective method, *i.e.* the burning of rice stubbles.The burning of crop residues releases heat, which helps to break down the remaining plant material, making it easier to clear the fields for subsequent planting.

From the farmers' perspective, burning also acts as a pest control measure, eliminating leftover straw and stubbles that could interfere with tillage and seeding operations (Reddy *et al.*, 2021). Due to labour scarcity and the lack of financial resources to acquire machinery for stubble management, burning becomes an attractive option.Additionally, the use of combine harvesters is prevalent in states like Punjab, Haryana, and Uttar Pradesh. These machines combine three tasks, namely, reaping, threshing, and winnowing, but their residue-scattering nature poses challenges for alternative residue management strategies.While stubble burning offers short-term benefits in terms of field preparation, it has become a cause of concern due to its negative impact on soil properties andits significant environmental, health and economic consequences.Wheat straw which serves as an excellent fodder does not pose as much of a problem. During the months of October and November, as much as 80% of the total rice straw produced on the farm is being burnt annually (Singh *et al*., 2010). Hence, management of rice residue requires a greater momentum for study.

Soil health is paramount for agricultural productivity as it serves as the foundation for successful crop growth and sustainable farming practices. A healthy soil ecosystem provides essential nutrients, water retention capacity and a supportive environment for root development, all of which are critical factors influencing plant growth and yield. Healthy soils contribute to improved water infiltration and drainage, reducing the risk of waterlogging and erosion.Stubble burning has adverse effects on soil health and fertility. The practice results in the loss of organic matter, nutrients and beneficial soil microorganisms, which are essential for maintaining soil structure, fertility and productivity. Studies have indicated that stubble burning can lead to changes in soil organic matter quality, affecting soil organic carbon, nitrogen and phosphorus levels (Virto *et al*., 2007; Bünemann *et al*., 2008). Stubble burning leads to the loss of essential nutrients in the soil, such as carbon and nitrogen, as well as phosphorus, potassium, and sulphur. (Koul *et al*., 2022). The elevated soil temperature due to burning can displace or kill important microorganisms, potentially disturbing the soil's carbon to nitrogen ratio equilibrium (Singh and Verma, 2021).  Moreover, the removal of crop residues through burning can increase soil erosion, compactionand degradation, leading to long-term declines in soil quality and agricultural productivity.

In recent years, concerns over the environmental and health impacts of stubble burning have prompted calls for alternative practices and mitigation measures.Different quantities of crop residues are left on the soil surface after harvest owing to different soil tillage practices (Gebhardt *et al*., 1985). Keeping this in mind, various approaches have been proposed to address the challenges posed by stubble burning, including the adoption of sustainable agricultural practices, such as conservation tillage, mulching and incorporation of crop residues into the soil. Additionally, governments and agricultural organizations have implemented policies, regulations and incentives aimed at reducing the prevalence of stubble burning and promoting alternative methods of crop residue management.

While stubble burning remains a common agricultural practice in many parts of the world, its environmental, health, and socioeconomic consequences highlight the need for more sustainable and environmentally friendly approaches to crop residue management.By promoting alternative practices and supporting farmers in adopting more environmentally sustainable methods, it is possible to mitigate the negative impacts of stubble burning and promote the long-term sustainability of agriculture.

This paperwill review the effect of stubble burning on various soil properties. It will explore the effects of stubble burning on soil fertility, organic matter content, soil microbial population and biodiversity. The findings from various papers will contribute to the ongoing debate on the use of stubble burning in agriculture and provide insights into sustainable agricultural practices that promote soil health and productivity.

**Air pollution**

One of the most pressing concerns associated with stubble burning is its contribution to air pollution. Air pollution due to this practice is quite evident as a thick combination of smoke and fogenvelops Delhi-NCR during October to November every year. The combustion of crop residues releases large amounts of particulate matter, carbon dioxide, carbon monoxide and other harmful pollutants into the atmosphere, leading to poor air quality and respiratory health problems for people living in affected areas.The implications of agricultural residue burning on human health is such that people with underlying respiratory disorders are more susceptible to the air pollution yielding severe health consequences (Long *et al*., 1998).The key pollutant of burning, which is particulate matter, $PM_{2.5}$, is reportedly raised from50 to 75%, while an increment of 40 to 45% in the concentration of $PM_{10}$is observed (Khan *et al*., 2023). One of the major contributors to greenhouse gas emissions is the agricultural sector, which accounts for about 17 to 32% (Bellarby *et al*., 2008). The emission of pollutants from stubble burning can have adverse effects on ambient air quality, depending on various factors such as composition, moisture content, and ambient conditions. Stubble burning has been linked to the release of harmful substances like benzene, which can pose risks to both environmental and human health (Kalbande *et al*., 2021). Release of soot particles, nitrogen oxides, sulphur dioxide, carbon dioxide, carbon monoxide and aromatic hydrocarbons by straw burning causes serious deterioration in the atmospheric quality and is hazardous to human health (Kumar *et al*., 2019). About 13 tonnes per hectare of carbon dioxide is produced along with other harmful air pollutants by instant burning depending on the composition of the residue (Mandal *et al*., 2004).Recent research has shown that employing zero tillage techniques combined with effective residue management can result in a 16% reduction in greenhouse gas emissions and a 78% decrease in carbon footprint compared to traditional farming methods(Kumar *et al*., 2021).

**Effect of residue incorporationand residue retention on soil properties**

While removal of residues by burning is usually associated with negative effects on soil properties, crop residues, if utilised well, have great potential to improve the physical, chemical and biological status of soil by need based employment of various strategies. The most viablealternative,that is residue incorporation and residue retentionbefore planting wheat, changes the soil microclimate and microbial population, leading to subsequent nutrient transformations in the soil (Kumar and Goh, 1999).Singh *et al*. (2008) suggests that immediately incorporating wheat and rice residues with a high carbon-to-nitrogen ratio before planting results in yellowing of the succeeding crop due to nitrogen immobilization, ultimately leading to reduced yields in subsequent crops due to nitrogen deficiency, development of toxic substances and require to be tilled more often. On the other hand, burning eliminates the harmful pests.Thus, the challenges of residue management should be met with scientific precision to explore its benefit to the maximum.Decomposition and mineralization of nutrients through residue incorporation can meet its purpose for the plant when straw is added in the soil at least three weeks before sowing or transplanting of the next crop which minimizes the negative effects of anaerobic decomposition (Olk *et al*., 2006).Prasad *et al*. (1999) reported that incorporation of rice and wheat residues improved the soil fertility by incrementing organic carbon, phosphorus and potassium contents. It was also found that residue incorporation did not have any detrimental effects on the growth of subsequent crop.

Kumar *et al*. (2004) reported through their two-year trial that incorporation of rice residue improved the growth and yield attributes leading to higher grain yield over the other treatments. Conventional tillage produced smaller grains while management of residue by deep tillage or conservation tillage yielded broader flag leaves. The organic carbon, available nitrogen, phosphorus and potassium was reportedly enhanced after wheat harvest by the retention of residue irrespective of tillage type.Gupta *et al*. (2007) through their experiment in the Indo-Gangetic Plains revealed that the grain yields of residue burned were at par with that of residue removed plots. Wheat yields increased upto 24 % with incorporation of rice residue alone. There was no evidence of nitrogen immobilization reported when rice straw was incorporated ten to forty days prior to wheat sowing. Grain yield of wheat in the treatment with incorporation of both rice and wheat straw was similar to that of the treatment with incorporation of rice straw alone. Correspondingly, Singh *et al*. (2004) revealed through residue decomposition studies that wheat residue incorporation on rice crop increased the yield from 0.18 to 0.37 Mg $ha^{-1}$ in a rice-wheat long term rotation and lowest yield values were recorded in residue removed and burnt plots. Rice residue incorporation improved the physiological efficiency of wheat crop in comparison to the residue burnt plot. Carbon accumulation also significantly increased in the residue incorporated plots.

Backing the data above, subsequent research also revealed that rice-wheat yields were highest by crop residue incorporation with nitrogen and potassium application as compared to crop residue removed and burnt.Rice yields increased from 3.0% to 8.2% in the treatments where straw was incorporated than where it was removed under different combinations of tillage practices. (Dotaniya *et al*., 2013; Nandan *et al*., 2018). Research conducted by Biswakarma *et al*. (2023) based on the impact of residue retention on soil properties in the context of integrated crop management practices for zero-tilled rice-wheat rotations opined that practices whichretain residues show significant improvement in soil quality index compared to conventional practices while also reducing carbon footprints ranging from 9.1% to 47%. To give an illustration (Table 1), Mandal *et al*. (2004) observed higher organic carbon content and availability of essential nutrients in the residue incorporated treatment in comparison to the residue burnt and removed treatments.

A pivotal impediment on the path of effective stubble management is the interplay between labor and machinery. While the vision of seamlessly integrating machinery into the process is appealing, the reality might be quite different. The availability and accessibility of appropriate machinery for optimal stubble management could be a stumbling block.Mechanical equipment like Happy Seeders, has been found to be highly effective in integrating straw into the soil, particularly during tilling activities (Singh *et al*., 2008). These machines are capable of mulching straw and performing tillage tasks with minimal disruption to the top layer of soil, as highlighted by Ravindra *et al*. (2018).The results of an experiment conducted by Dhillon (2016) showed that by using this technology, a total of ₹ 424.15, ₹ 366.25 and ₹ 1989 were saved on nitrogenous, phosphatic and potassic fertilizers respectively, totaling the amount to ₹ 2779.40 per hectare. It also showed improvement over the physical properties considering a longer time period. The state government offers a 50% subsidy for individual farmers and a 75% subsidy for the farmers' groups and cooperatives to encourage them to utilize this machinery.A comparatively recent invention is the Super Seeder. It is used to sow wheat in the field with standing stubbles after harvesting the paddy crop. No separate implement is required for seedbed preparation and sowing. All these operations along with straw management are done in a single operation. A rotavator and zero till drill is present in a super seeder to manage the paddy straw and sow wheat respectively. The rotavator cuts the standing stubbles, loose straw and incorporates it into the soil.

**Table 1**. Impact of different residue management practices (Mandal *et al*., 2004)

| **Soil property** | **Crop residue management** | | |
|---|---|---|---|
| | **Incorporated** | **Removed** | **Burned** |
| Organic carbon (%) | 0.75 | 0.59 | 0.69 |
| Available nitrogen (kg $ha^{-1}$) | 154 | 139 | 143 |
| Available phosphorus (kg $ha^{-1}$) | 45 | 38 | 32 |
| Available potassium (kg $ha^{-1}$) | 85 | 56 | 77 |
| Total nitrogen (kg $ha^{-1}$) | 2501 | 2002 | 1725 |
| Total phosphorus (kg $ha^{-1}$) | 1346 | 924 | 858 |
| Total potassium (kg $ha^{-1}$) | 40480 | 34540 | 38280 |

**Effect on crop yield**

The effects of residue incorporation on crop yield are backed by various studies. For instance, Goswami *et al*. (2020) found that incorporating rice residue early in a rice-rice system without nitrogen fertilizer led to a 13 to 20% increase in rice grain yields. Moreover, Madar *et al*. (2020)suggested that retaining 4-6 kg $ha^{-1}$ of crop residue in a no-tillage system significantly enhanced crop yield and soil quality indicators.Another study conducted by Ali *et al*. (2019) reported that among different crop residue management methods, incorporating residue notably boosted grain and straw yields of rice and wheat, with increased nitrogen, phosphorus and potassium uptake in wheat by 15%, 11%and 11%, respectively. Thind *et al*. (2019) demonstrated that retaining residue on the surface in zero tillage resulted in significantly higher wheat grain yields compared to conventional tillage with straw removal. Similarly, Nandan *et al*. (2018) observed increased rice and wheat yields with straw incorporation, with rice yields rising by 3.0% to 8.2% compared to straw removal across various tillage practices.

**Effect on soil organic carbon**

Organic matter plays a crucial role in soil fertility by providing essential nutrients, improving soil structure and enhancing water retention capacity.It promotes soil microbialactivity, contributes to increased productivity, nutrient use efficiencyand sustainability without degrading soil quality.Retention of carbon in arable soils is seen as a way to mitigate soil degradation and sustain crop productivity. (Bhattacharyya*et al*., 2015). Consequently, the decline in organic matter due to stubble burning can negatively affect crop productivity and overall soil health.Singh *et al*. (2020) conducted experiments involving zero tillage, conventional tillage, residue incorporation and burning treatments. Their findings indicated that burning rice residue is not a suitable method as it reduces the amount of carbon added to the soil's organic carbon pool, thus impeding carbon sustainability.

Desrochers *et al*. (2019) observed that the carbon and nitrogen content of coarse particulate organic matter was higher in the no-burn treatment compared to the burn treatment.The study by Ademe (2015) revealed that soil organic carbon and total nitrogen depletion in fields where crop residue was burned reached up to 83%. The changes were particularly notable in the top 30 cm of soil but were also significant up to a depth of 60 cm. However, deeper soil layers (45-60 cm) in burned and conventionally cultivated areas exhibited similar content, indicating that immediate impacts from fire or tillage were mainly confined to the upper soil layers.Gangwar *et al*. (2006) found that incorporating 5 tonnes per hectare of rice straw led to higher soil organic carbon levels and improved infiltration compared to burning the same amount of residue. Additionally, Dormaar *et al*. (1978) reported a significant reduction in organic carbon content after burning, and long-term wheat yields were greater in plots where stubble was not burned.

In a 19-year-old wheat-lupin rotation experiment conducted by Chan *et al*. (2002), it was found that loss of <53 μm fraction of soil organic carbon, which is usually difficult to break down due to its association with mineral soil (Hassink, 1997), was more prominent, thereby laying out clearly the extent to which burning can affect the organic carbon pools in the long run. Basir *et al*. (2017) conducted an experiment involving the effect of stubble management treatments on wheat over a period of two years and found that the least soilorganic carbon was noted for the stubble removal treatmentwith values statistically comparable with the burning treatment. A long-term experiment conducted by Gupta *et al*. (2023) concluded that organic matter improved the rice productivity by crop residue retention or incorporation and helped to reduce the nutrient loss by means of carbon transformation processes that resulted in the formation of carbon intermediates. The soil organic carbon was found to be the least in the residue burnt treatments for both rice and wheat.Memon *et al*. (2018) revealed that the average soil organic matter content significantly increased from 3.08 to 17.07 % under residue-incorporated treatments while it was significantly depleted in the residue burnt treatments.

**Effect on soil pH and nutrients**

Stubble burning results in the volatilization of nutrients such as nitrogen, sulphur and carbon, reducing their availability for plant growth and development and accreted ash and change the nutrient characteristics. This loss of valuable nutrients may necessitate the use of synthetic fertilizers to compensate for deficiencies, further contributing to environmental concerns.Nutrient availability is subject to change with the type of material that is introduced in the soil. The macronutrients nitrogen and phosphorus have low thresholds and are drastically affected by burning. For instance, stubble burning incurs large losses of up to 80%of nitrogen, 25% of phosphorus, 21% of potassium and 4-60% of sulphur (Lefroy *et al*., 1994). Singh *et al*. (2008) reported nutrient losses of 2400 kg carbon, 35 kg nitrogen, 3.2 kg phosphorus, 21 kg potassium and 2.7 kg sulphur in one hectare area due to burning of rice residues in Punjab.Translocation of compounds to the lower soil layers produced by combustion of organic matter on the surface may sometimes in contrast particularly increase the mineral nitrogen content there.According to Arunrat *et al*. (2023), even though stubble burning leads to significant increases in soil pH, electrical conductivity, available nitrogen, total nitrogen and soil nutrients (available phosphorus, potassium, calcium and magnesium) immediately after burning due to increased ash content in the soil, it can reduce soil fertility and organic matter content in the long run.Furthermore, stubble retention can increase soil acidity compared to stubble burning, while stubble burning has a liming effect on the soil.The nitrate-nitrogen can recover to pre-burning levels only after five years while an increase in the available potassium levels was found.Kaur *et al*. (2019) found that the pH increased from a mean value of 7.94 to 8.46 after rice residue burning which is correlated with enzyme activity. The electrical conductivity and organic matter content showed an upward trend while nitrogen and phosphorus content significantly reduced post burning.A study conducted by Thanh *et al*. (2016) reported that the incorporation of rice straw resulted in greater increase in soil organic carbon, soil pH and nutrient content but minimum nitrogen content increase when compared with ash accretion from burned straw.

Jain *et al*. (2014) reported a nitrogen loss of 0.315, phosphorus loss of 0.013 and potassium loss of 0.261 metric tonnes per year by burning of stubble in a rice-wheat cropping system. In contrast, short-term research conducted by Ogbodo (2011) revealed that burning of rice husk increased the pH due to higher calcium and magnesium content of ash while it also increased the nitrogen, phosphorus and potassium content in both the residue burnt and residue incorporated plot in comparison to the untreated plot.Sidhu and Beri (2005) obtained results which showed that over a long-term rice-wheat cropping system, the available potassium increased by burning in comparison to removal of residues. A value of 45 mg $kg^{-1}$ potassium was recorded with residue removal while 58 mg $kg^{-1}$ was recorded by burning. On the other hand, the available sulphur was recorded 55 mg $kg^{-1}$ in residue removed soil and 34 mg $kg^{-1}$ in residue burnt soil.

An experiment conducted by Sharma *et al*. (2001) reported that complete burning of rice residues resulted in losses of nitrogen, phosphorus and potassium upto 100, 20.1 and 19.8 percent respectively. The corresponding losses due to wheat straw burning was 100, 22.2 and 21.8 percent respectively. Micronutrient fractions are also bound to decrease in soil due to burning. Complete burning of rice and wheat straw resulted in loss of DTPA-extractable copper whereas the DTPA-extractable iron, manganese and zinc increased. Additionally, Bhat *et al*. (1991) reported that burning caused a reduction in the available nitrogen, phosphorus and potassium while the same increased with incorporation of residues by addition of about 6 tonnes per hectare of wheat residues and 12 tonnes per hectare of rice residues over a period of seven years. Moreover, Rashid (1987) found that burning increased the soil pH sharply on the burned surface while the subsoil showed more acidity.Ponnamperuma (1984) reported that the entire amount of carbon, 80 to 90 % of nitrogen, 25 % of phosphorus, 20 % of potassium and 50 % of sulphur present in crop residues were lost by burning crop residues.

**Effect on soil microbial communities**

Stubble burning has been associated with increased soil temperatures, which can impact microbial communities and soil biodiversity (Chawala and Sandhu, 2020). Furthermore, stubble burning reduces the availability of habitat and food sources for soil organisms, resulting in reduced soil biodiversity. The temperature of the soil can increase by up to 50-70°C in the uppermost 0 to 3 cm of soil, leading to a decrease in heterotrophic microorganisms by 77%. Burning rice straw and stubblecan have major effects on the microbial population and biodiversity of soil and reduces populations of bacteria, fungi, actinomycetes, phosphate-solubilizing microorganisms, potassium-solubilizing microorganisms, cellulose, and microbial enzymes.The relative abundance of certain microbial genera shifts significantly in response to burning, with some genera increasing immediately after burning but decreasing significantly after a year.The impact of stubble burning on bacterial soil communities varies depending on soil moisture levels and the duration of the burn. Burning under high soil moisture conditions and within a very short time causes no effect to the bacterial soil communities. However, population of specific communities such as *Bacillus*, *Conexibacter* and *Acidothermus* significantly decline after stubble burning, with lower levels observed one year after burning (Arunrat *et al*., 2023).Zhu *et al*. (2021) reported that the microbial biomass including archaeal and bacterial communities significantly diminished by burning.

Soil enzymes play an active role in all biochemical processes in soil. Soil enzymes are more related to organic matter levels and directly involved in organic matter mineralization, thus affecting carbon and nitrogen cycles.Research conducted by Gupta *et al*. (2022) reflected that the microbial biomass carbon, fungal count, bacterialcount, actinobacterial count anddehydrogenase activityincreased significantly over nostraw treatments, considering a period of fourteen years.Yadav (2020) obtained results which revealed that burning leads to loss of nitrogen and sulphur, reduction in microbial population and enzymatic activity and increase in soil pH and electrical conductivity which are not particularly conducive for plant growth. In addition, Kaur *et al*. (2019) reported that the activities of some important soil enzymes such as dehydrogenase, phosphatase and urease showed a downward trend. Chen *et al*. (2012) obtained results which showed reduction in activities of phosphatase and urease enzymes in the topsoil which was covered with burned straw. There were significant differences in soil enzyme activity before and after straw burning in the plough layer of upto 5 cm and small changes were recorded from 5 to 13 cm. Microbial quantity also declined severely in the upper soil layer. Furthermore, Alvear *et al*. (2005) reported that total organic carbon and nitrogen and microbial biomass carbon and nitrogen were significantly higher under no-tillage systems than in conventional tillage. Microbial biomass carbon and nitrogen were found closely related with β-glucosidase and other soil enzymes. Despite the short duration of the experiment, changes in biological activities occurred mainly in the upper soil layer of 0 to 50 mm depth.

In contrast, a long-term experiment conducted by Jha *et al*. (2022) over a period of fifty years did not align with previous studies, whereinhigher respiration rates were seen in treatments where stubble remained after harvesting, likely due to more organic material being available in the soil. However, in this study, there was not a notable difference in the overall organic carbon content between treatments where stubble was burnt and those where it was not. Past research using the same samples found a strong link between microbial carbon respiration and the microbial metabolic quotient, which was higher in burnt stubble treatments, indicating that microbes in those treatments were likely under more stress and converting a larger portion of available material into carbon dioxide, reducing carbon use efficiency.Rice *et al*. (1994) reported reduction in microbial biomass carbon and nitrogen by long-term burning but no significant effects were revealed by short-term burning.

**Effect on soil physical properties**

Stubble burning also contributes to soil structure degradation by removing organic residues that contribute to soil aggregation and stability. This can result in soil compaction, decreased porosity, and increased susceptibility to erosion, ultimately leading to reduced soil fertility and increased environmental degradation.Additionally, stubble burning disrupts the protective cover provided by crop residues, making the soil more vulnerable to erosion by wind and water. Without adequate ground cover, soil erosion becomes more prevalent, leading to the loss of topsoil, nutrients, and organic matter.Furthermore, the burning of stubble has been linked to changes in soil physical properties, such as soil aggregation, penetration resistance, and hydraulic properties (Yakupoğlu *et al*., 2022).For instance, Song *et al*. (2019) revealed that when conventional tillage without straw return was compared with conservation tillage, the macro-aggregates and micro-aggregates increased by 24.52%, 28.48% and 18.12% for small, medium and large aggregates respectively. No tillage coupled with straw return caused a significant increase in aggregate-associated carbon within all the aggregate fractions in the topsoil. Moreover, Edem *et al*. (2014) reported a higher coarse sand fraction in the burnt plot relative to the unburnt plot. Bulk density increase of 4% was found in soil burnt with 30 kg-$m^2$ of the dry biomass and a 9% increase was found in 90 kg-$m^2$ treatment.

The experiment conducted by Wang *et al*. (2010) revealed that the content of large macro-aggregates (>2000 μm) in no-tillage treatments significantly exceeded that in tillage treatments in 5-10 cm and 10-15 cm depths but not in 0-5 cm soil depth. Soil fungal species richness that significantly exceeded in 5-10 cm and 10-15 cm depths under no-tillage but the differences were not significant in 0-5 cmdepth. In addition, Malhi *et al*. (2007) reported that combination of conventional tillage with residue burning leads to deterioration of soil properties. Large sized aggregates significantly reduced with 34.9% being the highest proportion in burnt plots while in zero tillage and no burning system, 47.1% resulted as the highest proportion of these aggregates. Furthermore, Virto *et al*. (2007) observed that no tillage stubble burning affected the aggregate size distribution by manner of consistently showing larger amounts of water-stable macro-aggregates (0.250–2.0 mm and >2.0 mm) and fewer micro-aggregates (<0.250 mm) after wet sieving. The bulk density was significantly higher and total porosity was significantly lower in burned plots (Singh *et al*., 2005).

Wuest *et al*. (2005) reported that wheat residue burning caused significant reduction in the earthworm population in burned plots while also degrading the water stability of the entire soil.

However, experiments carried out by Valzano *et al*. (1997) opined that in a direct drilled system, volumetric water content, bulk density, clay dispersion and aggregate stability had no significant differences between burned and unburned plots thereby stating no short-term ill-effects of burning on some physical properties.

**Conclusion**

In conclusion, stubble burning has been shown to have diverse and significant effects on soil properties, soil fertility, soil organic matter and environmental quality. The importance of considering alternative practices to stubble burning to mitigate these negative impacts and promote sustainable soil management practices is a dire need. While stubble burning is a common practice in many agricultural areas, but its effects on soil fertility and organic matter content are still poorly understood.Based on the above considerations, crop residue burning causes disruption of soil ecosystems which can impair nutrient cycling processes, decrease soil fertility and compromise ecosystem resilience, contributing to long-term degradation of soil health and productivity while the short-term effects are yet to be understood on a varied and broader level. Raising awareness among the stakeholders about the environmental and economic benefits of alternative stubble management methods is paramount. This necessitates targeted educational campaigns addressing the barriers to adoption, including access to resources and knowledge gaps.

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