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REVIEW ARTICLE

A Comprehensive Examination of the Influences of Agricultural Crop Residues on the Characteristics and Qualities of Soil

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ABSTRACT
This comprehensive review explores the critical role of agricultural crop residues and their impact on soil properties. Globally, billions of tonnes of crop residues are produced annually, with their management becoming an increasingly pertinent issue in sustainable agriculture. Traditionally considered waste, the utilization of these residues in farming systems has garnered recognition due to their influence on soil health and crop productivity. Fire also plays a significant role in affecting soil structure and aggregation, necessitating appropriate guidance for improving these soil characteristics. Immediate and effective response to fires is crucial for environmental protection. This review paper provides an in-depth analysis of the influences of crop residues on the physical, chemical, and biological properties of the soil. Physically, crop residues aid in soil protection by reducing erosion and improving moisture retention. Chemically, these residues contribute to soil fertility through nutrient cycling, as they decompose and release essential nutrients into the soil. Biologically, they influence soil microbial activity, supporting a diverse and active soil microbial community essential for nutrient cycling, organic matter decomposition, and disease suppression.
Keywords: *Crop residues; soil quality; crop productivity; agriculture sustainability.*

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INTRODUCTION

The global agricultural landscape is rapidly evolving, and with this evolution comes the increased recognition of sustainable farming practices. One such practice, the application of crop residues, has been identified as a key element in fostering sustainability and resilience in farming systems. This review paper seeks to critically examine the multifaceted impacts of these agricultural crop residues on the properties and qualities of soil. As societies have progressed economically and witnessed improved living standards [1], crop residues, once valuable sources of energy and animal feed obtained from living crops, have undergone a transformation. They are now commonly regarded as agricultural wastes. To paint a comprehensive picture of this subject, it is important to explore the nature of crop residues, understand their role in agricultural systems, and critically assess their impacts on soil properties. Crop residues encompass a wide array of organic matter left in the field following the harvest of crops. These residues can include stalks, leaves, husks, and roots, among other materials. Globally, the production of crop residues is substantial, running into billions of tonnes each year. Their management, thus, constitutes a significant aspect of modern farming systems. Numerous studies have consistently highlighted the positive effects of incorporating crop residues into the soil [2–4]. These benefits primarily revolve around enhancing soil quality and effectively remediating soil contamination. Traditionally, these residues were viewed as waste or by-products of agricultural processes. However, with the evolution of agricultural science and the advent of more sustainable farming techniques, their importance has been redefined. Crop residues are now recognized not only as an integral part of the farming system but also as a potential resource for enhancing soil health and crop productivity, making their management a critical concern in contemporary agriculture. One of the primary functions of crop residues in agriculture is their role in protecting the soil. Left on the field, these residues can help reduce soil erosion by acting as a protective layer, shielding the soil from the impact of rain and wind. This is particularly significant given that soil erosion constitutes a major threat to agricultural productivity, resulting in significant loss of fertile topsoil and degradation of agricultural land. Moreover, the protective layer formed by residues also aids in moisture retention by reducing evaporation, thereby improving soil water holding capacity. Apart from physical protection, crop residues also contribute to the enhancement of soil fertility. As these residues decompose, they release vital nutrients into the soil, which are essential for plant growth. Nutrient cycling, facilitated by the decay of crop residues, thus forms a crucial part of the nutrient dynamics in agricultural ecosystems. However, the impacts of crop residues on soil properties are not confined to the physical and chemical aspects. They extend to biological facets as well. Crop residues serve as a source of food for soil microorganisms, thus influencing the soil's biological activity. A diverse and active soil microbial community is a hallmark of healthy soil, playing an integral role in processes such as nutrient cycling, organic matter decomposition, and disease suppression [5]. Notwithstanding these potential benefits, the use of crop residues in agricultural systems is not devoid of challenges. For instance, the decomposition of crop residues may result in temporary nutrient immobilization, particularly of nitrogen, which could potentially impact the nutrient availability for subsequent crops. Moreover, residues can also serve as a habitat for pests and pathogens, thereby posing a risk of disease transmission. Therefore, a nuanced understanding of these aspects is vital for the effective management of crop residues in agriculture. In light of the above, it is clear that crop residues hold a significant position in sustainable farming practices. However, their impacts on soil properties, both positive and negative, necessitate a comprehensive examination, in order to devise strategies for effective management. This paper, therefore, aims to provide an in-depth review of the influences of agricultural crop residues on soil properties, thereby contributing to the broader discourse on sustainable farming systems. The following sections of the review delve into the impacts of crop residues on the physical, chemical, and biological properties of soil, providing a detailed overview of the current state of knowledge on the subject. This review will also critically examine potential adverse effects, thereby providing a balanced perspective on the subject. It is our hope that this review will stimulate further research into optimizing the use of crop residues in agricultural systems, ultimately contributing to the advancement of sustainable farming practices. The insights provided in this paper highlight the significance of further research aimed at optimizing the use of crop residues in agricultural systems, underscoring their role in fostering agricultural sustainability.

Exploring the Physical Properties and characteristics of Soil

A novel product involves the incineration of plant residues, a practice which, while seemingly efficient, could increase the soil's vulnerability to erosion and moisture loss, especially during the planting phase. This is of particular concern considering the pivotal role of soil health and integrity in supporting successful crop cultivation and overall agricultural productivity. Experimentally, this has been demonstrated in cases where wheat straw was incinerated. Results showed a noticeable increase in both the weight and bulk electrical conductivity of the soil. Electrical conductivity is a reliable measure of the concentration of soluble salts in the soil, and an increase in this parameter could potentially alter the soil's chemical properties, leading to imbalances that could affect plant growth. Further to this, the burning of cereal straw has been associated with a decrease in the stability of soil aggregates. Soil aggregates, which are clusters of soil particles, are integral to maintaining the soil structure. When the stability of these aggregates is reduced, the soil can become more prone to compaction and erosion, impairing its function as a medium for plant growth. Of particular note is a study that examined the difference in pore size distribution in soils where straw was burnt compared to those managed under conventional tillage practices. The findings indicated that the soil from areas where straw was burnt had 4.1 times more large pores, those greater than 1.5 mm, compared to conventionally tilled soils [6]. This higher incidence of large pores could amplify the soil's vulnerability to rapid moisture loss, creating conditions that are less than ideal for seed germination and root growth. In conclusion, while incinerating plant residues might seem an effective method for dealing with agricultural waste, it is important to understand its potential impacts on the soil. The associated increases in soil weight and electrical conductivity, the decrease in aggregate stability, and the changes in soil pore distribution all serve to underline the potential risks of this practice to soil health and, ultimately, agricultural productivity.

Exploring the chemical Properties and characteristics of Soil

Crop residue burning has been demonstrated to increase the pH of soil, indicative of a shift towards more alkaline conditions. This change in pH is intrinsically linked to an increase in soluble salts in the soil, a condition which could affect the soil's overall fertility and the capacity of plants to absorb necessary nutrients. Elevated soil salinity can disrupt the water uptake mechanism in plants, leading to lower crop yields. The practice of straw burning has also been shown to significantly reduce soil organic matter. Organic matter is a crucial component of soil as it contributes to its fertility, structure, and ability to hold water and nutrients. The loss of organic matter due to burning can, therefore, undermine these important soil functions [7].

In addition, the incineration of crop residues results in a decrease in the content of water and fat-soluble compounds and hemic acids in the soil. These components play an essential role in the health and productivity of the soil ecosystem. They aid in nutrient cycling and contribute to the stability and fertility of the soil. Their reduction could potentially disrupt the normal functioning of soil, impairing its ability to support plant growth effectively. The effects of stubble burning on soil nutrient availability are influenced by a variety of factors. These include the intensity of the fire, the type of soil, and climatic conditions. Experimental burns conducted on wheat straw have shown a decrease in the amount of nutrients available to plants as early as two weeks post-burning. This suggests that the impact of crop residue burning on soil fertility can be immediate and potentially long-lasting, necessitating careful consideration and management. Furthermore, the practice of burning stubble has been found to reduce the concentrations of phosphorus and potassium in both the soil and the surrounding seed environment. Phosphorus and potassium are among the primary nutrients necessary for plant growth. Phosphorus is critical for energy transfer and storage in plants, while potassium regulates various plant processes, including water regulation and disease resistance. Reduction in these crucial nutrients could negatively affect plant growth and crop yield. A comparative study between the burning of wheat and sorghum straw and their incorporation into the soil revealed a significant decrease in soil potassium levels in the former case. This reduction in a critical nutrient again underscores the potential negative impact of burning crop residues on soil health and productivity. Moreover, certain studies indicate that burning crop residues can decrease the soil's cation exchange capacity. The cation exchange capacity is a measure of the soil's ability to retain and supply cations (positively charged ions) to plant roots. A lower cation exchange capacity would mean that the soil has a reduced capacity to supply essential nutrients to plants, thereby potentially diminishing crop yields. In conclusion, the incineration of crop residues has been found to have several potentially adverse effects on soil health and fertility. These include an increase in soil pH and soluble salts, a decrease in organic matter and essential nutrients, and a reduction in the soil's cation exchange capacity. While the practice might be seen as a convenient method of dealing with agricultural waste, the potential negative impacts on the soil and its ability to support plant growth necessitate a careful re-evaluation of this approach. Emphasizing more sustainable practices that maintain or enhance soil health, such as incorporating crop residues into the soil instead of burning, could have far-reaching benefits for agricultural productivity and sustainability.

Analyzing Soil Microbial Characteristics and Biochemical Attributes

Soil microbial and biochemical attributes provide key insights into the soil's health, and understanding how these characteristics are influenced by the management of crop residues is of paramount importance. Soil microorganisms are integral to the soil ecosystem, facilitating nutrient cycling, organic matter decomposition, and disease suppression. Furthermore, they contribute significantly to the soil's biochemical properties, making them instrumental in sustaining soil fertility and productivity. Crop residues, being rich sources of organic matter, can markedly impact these soil microbial and biochemical attributes. When incorporated into the soil, crop residues serve as a food source for various soil microorganisms, including bacteria, fungi, and actinomycetes, among others. As these microorganisms decompose the residues, they not only multiply, enhancing the soil's microbial biomass, but also transform the organic matter into humus and nutrients that can be easily absorbed by plants. In terms of biochemical attributes, the decomposition of crop residues stimulates enzymatic activities in the soil. Enzymes, being biological catalysts, expedite biochemical reactions, including those involved in the cycling of key nutrients such as nitrogen, phosphorus, and sulphur. Increased enzymatic activity, therefore, can enhance nutrient availability in the soil, benefiting plant growth and crop yield. Moreover, the incorporation of crop residues can bolster the soil's microbial diversity. A diverse microbial community is more resilient to disturbances and is better equipped to perform various soil functions, thereby contributing to the soil's overall health and productivity. Diverse soil microbial communities can also suppress plant pathogens, reducing the need for chemical pesticides and contributing to more sustainable farming practices. Burning crop residues on the soil surface has been observed to result in a decrease in the soil's microbial population. For example, when wheat straw is burnt, there is a reduction in the bacterial population by up to 50% in the upper 2.5 cm of the soil. This reduction can potentially impact the soil's fertility and its ability to support plant growth, given the crucial role that soil microorganisms play in nutrient cycling and organic matter decomposition. Interestingly, the soil microbial population in plots where wheat straw was burnt and incorporated into the soil was approximately 70% higher compared to plots where the straw was merely mixed into the soil. This suggests that the way crop residues are managed can influence the soil's microbial dynamics. Following crop residue burning, it has been observed that bacterial residues in the soil tend to be more prevalent than fungal residues. This could alter the balance between different types of soil microorganisms, potentially impacting soil health and function [8]. In addition, burning crop residues can decrease the activity of enzymes involved in the mineral cycling within the soil. These enzymes play a critical role in transforming nutrients into forms that can be readily absorbed by plants. A reduction in their activity could, therefore, affect the availability of nutrients in the soil, potentially impacting plant growth and crop yield. However, in certain regions of the world, such as the Pacific Northwest, burning plant residues is seen as an effective and cost-efficient method of pathogen control. For instance, burning wheat straw in fields has been shown to reduce the population of various species of pathogenic fungi, including those belonging to the Pythium genus, by 40 to 50 percent. This could have significant implications for disease management in crops. Despite these potential benefits, burning crop residues can have certain negative effects. The heat generated from burning can cause some chemicals to disrupt dormancy, potentially inhibiting seed germination or causing seed loss. In one study, it was found that burning crop residues reduced the density of wild oats to 13 plants per square meter. In another experiment, it was observed that burning small grain stubble significantly reduced the density of an ancestral wheat weed species (Aegilops cylindrica). This indicates that burning crop residues can also influence weed dynamics, with potential implications for weed management in agricultural systems. Overall, while burning crop residues can have certain benefits, such as pathogen and weed control, it can also have potential negative impacts on soil microbial populations and nutrient cycling. Therefore, a careful evaluation of these potential trade-offs is necessary when considering the use of this practice in managing crop residues [9]. However, it's worth noting that while the addition of crop residues generally has a positive impact on soil microbial and biochemical characteristics, the specific effects can vary depending on factors such as the type of crop residue, its decomposition rate, and the local soil and climatic conditions. For instance, residues from leguminous crops, which decompose faster and are rich in nitrogen, can have different impacts on the soil's microbial and biochemical attributes than residues from cereal crops. In conclusion, understanding the impacts of crop residues on the soil's microbial and biochemical characteristics can provide valuable insights into how to manage these residues to improve soil health, crop productivity, and the sustainability of agricultural systems. Further research in this area is crucial to refine management practices and to understand the long-term effects of crop residue management on these key soil properties.

Impacts of Fire on the Biological Functions of Soil

Our current understanding of the effects of fire on soil biological activity remains limited. However, it is widely reported that fires lead to a decrease in both soil organic matter and biological activity. One proposed mechanism for this reduction in microbial activity is the incineration of microorganisms during a fire event. Post-fire, organic matter can be reintroduced to the soil through plant growth, thereby providing a food source for the recovering soil microbial communities, including those in previously unburned areas. However, the reduction of soil organic matter due to fire significantly limits this food source for soil microbes. Scientific studies suggest that microbial processes are responsible for the oxidation of about 80% of plant residues, with the remaining 20% being transformed into organic compounds. These easily-degradable compounds spur the production of microbial biomass, subsequently enhancing soil biological activity. When plant residues are burned, approximately 60% of the carbon is immediately released as carbon monoxide, with the remaining 40% partly entering soil microbial processes (about 32%) and being transformed into organic matter (about 8%). The carbon present in the resultant ash cannot function as a food source or substrate for microbes. Consequently, microbial activity and population size decrease, leading to a disruption in soil biological processes [10]. In an experimental setup, plant debris and ash from burned residues were added to pots filled with loamy soil. These pots were maintained at field capacity for 10 days at 24°C. Microbial activity was then assessed in these pots, with the findings revealing significantly higher microbial activity with the addition of plant debris than with ash. Notably, the addition of plant residues resulted in immobilization of a substantial amount of nitrogen in the soil due to a high carbon to nitrogen ratio (C/N). In contrast, soil nitrogen became more available when ash was added, as ash lacks organic matter that soil microbes can use as a food source. As a result, microbial populations declined, leading to a reduction in nitrogen immobilization by soil microbes [11]. The incineration of plant residues can also influence the composition of microbial communities. For example, the activity of fungi, which play a key role in decomposing plant debris, can be more impacted than that of bacteria. This suggests that a significant proportion of fungi in the soil population contributes to soil quality. However, burning plant residues can deplete this fungal food source, leading to a decline in the fungal population and a shift towards bacterial dominance. In addition to the loss of soil organic matter, the reduction in soil porosity and permeability post-fire can negatively affect moisture retention and soil structure, further impacting the fungal population.

Impact of Fire on the Soil Properties

Fire incidents, whether occurring naturally or instigated anthropogenically, have a profound impact on soil properties. From physical parameters to chemical composition, and biological life within the soil, fire influences soil characteristics on multiple levels. Several key attributes, including structure, aggregation, mechanical strength, and bulk density, are central to understanding the physical characteristics of soil. Fire has a direct impact on these parameters, primarily through the destruction of organic matter, which in turn adversely affects soil structure and granulation. The loss of organic matter leads to a decrease in the correlation between soils and their associated low soil pore spaces. Fire promotes the formation of more compacted soil aggregates, due to the reduction of organic material. However, this compactness diminishes over time as the soil is subjected to mechanical forces, such as those from machinery used in farming. Moreover, the reduction in organic matter results in increased soil bulk density and decreased soil porosity. These alterations have consequential impacts on plant and microorganism growth due to changes in soil aeration and gas exchange. The decreased adherence between soil particles, triggered by these shifts, leads to the formation of larger clumps during ploughing. This necessitates additional tillage, resulting in increased soil compaction, a condition that poses further challenges to agricultural practices [12]. Physically, fire alters soil structure, permeability, and water-holding capacity. High temperatures incite the combustion of organic matter, leading to soil particles losing their aggregate structure and becoming more prone to erosion. This consequently impairs the soil's ability to retain water, impacting its water-holding capacity. Chemically, fire induces changes in the soil's nutrient content. While an immediate post-fire effect can be a surge in available nutrients due to the ash deposit, these nutrients are highly soluble and can be leached away swiftly, leading to nutrient-poor conditions in the long run. Fire can also lead to an increase in soil pH, particularly in soils that were originally acidic, due to the production of basic cations like calcium, potassium, and magnesium. Biologically, fire affects soil microorganisms by causing a reduction in microbial biomass, diversity, and activity, primarily due to the high temperatures associated with fire. Microorganisms play crucial roles in nutrient cycling and organic matter decomposition, hence a decline in their populations can significantly disrupt soil functions. In addition, the reduction in soil organic matter following a fire limits the food source for soil microbes, further hindering their recovery post-fire. The specific impacts of fire on soil properties can vary depending on several factors, including the intensity and frequency of fire, the pre-fire soil conditions, and the type of vegetation involved. Post-fire recovery of soils is also influenced by these factors, in addition to local climatic conditions and management practices. To summarize, fire substantially impacts soil properties, influencing its physical structure, chemical composition, and biological life. A deeper understanding of these impacts is vital for soil management, particularly in fire-prone ecosystems. Further research is required to better understand these impacts and develop effective strategies for soil conservation and restoration post-fire.

Impacts of Fire on Crop Health and Yield

Fire has significant, multi-dimensional effects on crop health and productivity. These effects stem from the direct impacts of fire on the plants themselves and from the secondary influences of fire on the soil properties essential for crop growth. In terms of direct impacts, fire can cause immediate physical damage to crops, leading to loss of yield. High temperatures can damage plant tissues, inhibit photosynthesis, and cause water loss, thereby affecting plant health and productivity. Furthermore, intense heat can cause seed sterility, disrupting the reproduction and perpetuation of crop species. The secondary, and often more enduring, effects of fire on crops come from the alterations it causes to the soil environment. Fire influences several soil properties, such as structure, aggregation, nutrient content, biological activity, and water-holding capacity. These alterations can indirectly influence crop health and yield. For instance, the combustion of organic matter during a fire event can lead to increased bulk density and reduced porosity, disrupting the soil structure and impeding root penetration and growth. Such changes can negatively impact the crops' access to essential resources, including nutrients and water. Numerous researchers have extensively studied the influence of organic inputs on various soil physical properties over time, including aspects such as soil aggregate stability, bulk density, and water retention as reported by Zhang and Peng, 2006; Singh *et al*., 2007; Fuentes *et al*. [13-15]. It's been observed that incorporating organic matter into the soil enhances aggregate stability, with the increase varying from 1.1 to 10.0 times, and this amplification is closely tied to the dynamics of the decomposition of the added inputs [16]. Aggregate stability is a crucial characteristic of soil as it plays a significant role in curbing soil erosion. In a detailed four-year study, Heard J and colleagues [17]), discovered that the integration of straw into the soil led to an increase in the proportion of larger soil aggregates: by 3% for aggregates larger than 38 mm and 1% for those between 12.7 and 38.0 mm in size. Concurrently, it decreased the proportion of aggregates susceptible to wind erosion by 1% for sizes between 0.42 and 0.83 mm and 3% for those smaller than 0.42 mm. In their research, they also found that the combination of straw retention (SR) and no-till farming practices (NT) resulted in a considerable reduction in the proportion of wind-erodible aggregates (by 34%) while simultaneously increasing the proportion of larger aggregates (by 37%). The nutrient content of the soil can also be significantly affected by fire. While fire can initially increase the availability of some nutrients due to the deposition of ash, these nutrients are often rapidly lost through leaching and erosion, leading to long-term nutrient deficits in the soil. This nutrient loss can limit crop growth and development, resulting in reduced yield. Additionally, fire influences soil biological activity, particularly the abundance and activity of soil microorganisms crucial for nutrient cycling and organic matter decomposition. The reduction in microbial populations post-fire can hinder these important soil processes, further exacerbating the nutrient limitations for crops. In summary, fire can have detrimental effects on crops, both directly and indirectly through changes in soil properties. A deeper understanding of these effects is crucial for developing strategies to mitigate fire impacts and ensure the sustainability of crop production, particularly in fire-prone regions.

DISCUSSIONS AND CONCLUSIONS

In the context of crop residue management in countries, especially in the northern regions, where straw burning remains a prevalent practice, the identification and adoption of reduction technologies is increasingly recognized as a crucial measure for ensuring agricultural ecological sustainability. Integration of successful technologies into conservation tillage systems, encompassing no-tillage and minimum-tillage practices, is expected to mitigate some of the problems associated with straw burning. These practices aim to maintain adequate levels of crop residues or plant debris on the soil surface, which in turn help in soil conservation. Crop residue burning, however, continues to be a topic of controversy. It is a double-edged sword with the immediate benefits of increased production owing to the release of nutrients and the long-term detriments of reduced soil productivity. Short-term fire incidents have been reported to enhance soil fertility and nitrogen content, but these fires can also harm microorganisms and create competition for nitrogen in the top 5 cm of soil. With crop residues on the soil surface, the adverse effects of wind and water erosion remain minimal. Farmers often resort to burning residues primarily to control pests and weeds, and to expediently clear the land prior to the next cycle of cultivation. Yet, extensive research suggests that strategic crop rotation and judicious use of pesticides can be far more beneficial. Crop residues can be managed without resorting to burning, and action plans for such strategies can be formulated. While burning offers certain benefits, such as control over weeds and insects, its drawbacks include soil erosion, loss of soil organic matter, alterations to soil permeability and structure, and disruption to the balance of soil microorganisms. These disadvantages can contribute to long-term declines in crop yields in some regions. The practice of crop residue burning has been implicated in approximately 75% of air pollution incidents recorded last summer, revealing its negative environmental impact. The long-term implications of this practice, when viewed from a disadvantageous perspective, suggest that soil quality and, consequently, crop growth can suffer irreparable damage over time. Workshops aimed at educating farmers about the harmful effects of crop residue burning, along with the provision of equipment for residue management, can serve as effective strategies. Training farmers in pest and weed management techniques and familiarizing them with alternate residue management methods, such as mulching and ploughing, are crucial for reducing residue burning. The heat generated from burning crop residues not only negatively impacts soil structure, but also provides favourable conditions for weed proliferation. Stubborn beliefs among farmers that straw burning improves soil fertility must be addressed with appropriate education to debunk such misconceptions. Furthermore, the air pollution caused by straw burning, which often results in long columns of smoke and ash in surrounding towns and villages, poses significant environmental and health concerns. Instead of burning residues to control pests and weeds and to prepare the land for the next planting season, it's essential to adopt more environmentally-friendly and sustainable farming practices.

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