Impacts of crop residues on soil health: a review

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ABSTRACT
Crop residues are mainly post-harvest remains of agriculture. The organic matters, nutrients, and hollow structures of crop residues enable them to be applied in agriculture. In this review, we summarize the impacts of crop residues on soil health. Crop residue returning is beneficial to soil physicochemical properties. Soil water content, total porosity, aggregate stability, cation exchange capability (CEC), organic carbon, phosphorus, and potassium all increased after being amended with crop residues. The negative effects of allelochemicals from crop residues on crop growth can be adjusted by crop residue returning management. The rice straw has positive impacts on soil microbial properties. Besides, crop residue play a crucial part in soil remediation. Crop residues as soil amendments have inhibitory effects on some heavy metals, organic pollutants, and pathogens. They can also alleviate the pressure of saline-alkali soil. Finally, we provide some suggestions for improving soil health with crop residues.

1. Introduction

The amount of crop residues is increasing every year following the population size. The total amount of crop residues produced in the world is 2445.2MT, and 42.5% was produced in China, as summarized in Table 1. However, crop residues have been transformed from previously living energy and animal feed into agricultural wastes due to economic development and improved standards of living [1]. Crop residues are rich in nutrients and can be decomposed by microorganisms. Therefore, returning crop residues to the soil rather than burning them is strongly encouraged to minimize air pollution in China. At present, about 50% crop residues are returned to soil every year in China [2]. Returning crop residues to soil with proper method is beneficial to the soil health, which is conductive to the green development of agriculture.

Soil is prone to degradation or decline in its quality due to misuse by the agricultural industry, such as a monoculture of crops, over application of chemical fertilizers, and pesticides and/or herbicides. In addition, soil is contaminated by anthropogenic activities, such as mineral resource exploiting and smelting, metal electroplating, paint and coating processing, and electronic equipment manufacturing [3–5]. Many studies have reported that crop residue incorporation has benefits on the improvement of soil quality and remediation of soil contamination [6–8].

Nevertheless, the decomposition of crop residues does not always translate into such benefits. For example, it can increase pest and disease pressure [9]. Rice straw cover can increase dissolved organic carbon loss from the plots, which may impose negative impacts on the soil environment and groundwater [10]. Rice straw amendment (1% w/w) can increase methylmercury levels in wheat (by 225%) and rice (by 20%) grains in Hg-contaminated paddy soil [11].

The effects of crop residue returning are related to the types of residues, the return ratios, the return methods, tillage intensity, fertilization rate, the climate conditions, and soil characteristics [12,13]. Therefore, the inclusion of crop residues into soil requires appropriate management strategies that support crop production and soil health. In this review, the composition, the nutrient content, the physical structure of crop residues, and the effects of residues on the soil improvement and remediation are clarified. Good understanding of these effects is essential to sustainable management of agriculture and environment.

2. Characteristics of crop residues

2.1. Composition

Crop residues are mainly composed of cellulose (40–50 wt%), hemicellulose (15–25 wt%), lignin (20–30 wt%), protein, and soluble sugars (glucose, fructose, et al.). The composition characteristics of crop residues are summarized in Table 2 [14]. Cellulose is a biopolymer composed of monomeric glucose unit bonded with 1,4-β-glycosidic linkage. It is presented in the form of parallel-aligned microfibril chains in the plant cell wall linked by hydrogen bonding among the
chains. Hemicellulose has complicated composition (xylans, xyloglucan, arabinoxylans and glucomannans). Lignin is a phenolic complex polymer formed by cross-linking of three major components: p-coumaryl, coniferyl, and sinapyl alcohols. In cell walls, cellulose is surrounded by a monolayer of hemicellulose and embedded in a matrix of hemicellulose and lignin, which form stable complex 3-dimensional structure (Figure 1) [15–17].

Table 1. Crop residues produced in the world and China [1].

| Raw Material | World Crop Residues (MT) | China Crop Residues (MT) |
|--------------|--------------------------|--------------------------|
| Corn stalks  | 28                       | 2445.2                   |
| Rice         | 544                      | 1039.5                   |
| Wheat        | 600                      | 180                      |
| Sugarcane    | 102                      | 36                       |
| Bagasse      | 89                       | 28                       |
| Cotton       | 544                      | 149                      |
| Bales        | 2445.2                   | 1039.5                   |

2.2. Nutrient content

As a carbon-rich biomass, crop residues contain carbon (40%-45%), nitrogen (0.6%-1%), phosphorus (0.45%-2%), potassium (14%-23%), and microelements, which are necessary for crop growth (Table 3) [14]. They help alleviating imbalances of nutrients in farm soil and making up for drawbacks of inorganic fertilizers. The release rate and content of nutrient are related to the properties of crop residues (C/N ratio and chemical composition), the climate (temperature and moisture), the soil conditions (pH and water content) and the method of applying crop residues into soil (direct and indirect) [15]. Usually, it is assumed that C/N ratio greater than 25:1 leads to the rapid immobilization of inorganic nitrogen while lower C/N ratio results in mineralization. Warm temperature and appropriate soil moisture can potentially improve the decomposition of crop residues and nitrogen release [18].

Table 2. Statistical results for the different crop residue composition characteristics (on a dry basis).

| Properties | Rice straw | Wheat straw | Corn stover | Rape stalk | Cotton stalk |
|------------|------------|-------------|-------------|------------|--------------|
| C (%)      | 40.74 ± 1.76 | 42.1 ± 1.19 | 43.86 ± 1.31 | 42.93 ± 1.62 | 45.83 ± 1.71 |
| N (%)      | 0.79 ± 0.27 | 0.60 ± 0.15 | 1.00 ± 0.25 | 0.77 ± 0.32 | 1.12 ± 0.23  |
| P (%)      | 1.97 ± 2.17 | 0.45 ± 0.22 | 0.95 ± 0.49 | 0.78 ± 0.51 | 1.40 ± 0.58  |
| K (%)      | 17.41 ± 6.38 | 23.45 ± 7.68 | 17.73 ± 7.00 | 14.66 ± 6.15 | 12.64 ± 3.98 |
| S (%)      | 0.36 ± 0.12 | 0.37 ± 0.11 | 0.39 ± 0.22 | 0.62 ± 0.19 | 0.42 ± 0.24  |

Figure 1. Structure and composition of crop residues.

Table 3. The nutrient content of crop residues (on a dry basis).

| Properties | Rice straw | Wheat straw | Corn stover | Rape stalk | Cotton stalk |
|------------|------------|-------------|-------------|------------|--------------|
| C (%)      | 40.74 ± 1.76 | 42.1 ± 1.19 | 43.86 ± 1.31 | 42.93 ± 1.62 | 45.83 ± 1.71 |
| N (%)      | 0.79 ± 0.27 | 0.60 ± 0.15 | 1.00 ± 0.25 | 0.77 ± 0.32 | 1.12 ± 0.23  |
| P (%)      | 1.97 ± 2.17 | 0.45 ± 0.22 | 0.95 ± 0.49 | 0.78 ± 0.51 | 1.40 ± 0.58  |
| K (%)      | 17.41 ± 6.38 | 23.45 ± 7.68 | 17.73 ± 7.00 | 14.66 ± 6.15 | 12.64 ± 3.98 |
| S (%)      | 0.36 ± 0.12 | 0.37 ± 0.11 | 0.39 ± 0.22 | 0.62 ± 0.19 | 0.42 ± 0.24  |


2.3. Physical structure

Crop residues have distinctive tubular structure and thick wall with light weight. Their hollow structures are composed of cell walls and abundant pores (Figures 2, Figure 3). Pore structure characteristics mainly include specific surface area, pore volume and pore size distribution [19]. Different types of crop residues have different pore structures. The rice straw interior structure has a large number of vascular bundle sheaths, medullary cavities, intercellular canals, and other porous tissue, which has low specific surface area (0.77 m²/g) and pore volume (0.0059 m³/g) [20,21]. Wheat straw has a linear multi-cavity structure, which can bridge between the pores, making the connectivity of the porous network structure more complex [22]. The average pore size of wheat straw is 13.90 nm and the cumulative pore volume is 0.01 cm³/g [23]. Nanometer-sized pores (5–100 nm) are the main pores in corn stalks. The total pore area

Figure 2. SEM images of rice straw (a: ×500; b: ×1000) and cotton stalks (c: ×500; d: ×1000).

Figure 3. Bulk density of different crop residues.
is 31.88 m$^3$/g and the porosity is 73.33% [24]. Cotton stalks mainly consist of macropores and have a very low specific surface area (1.95 m$^2$/g) and total pore volume (0.0115 m$^3$/g) [25].

Bulk density reflects the tightness of crop residues, which varies with the types and uniformity of crop residues. Hollow stems and low-density outer epidermis make the bulk density of wheat straw extremely small. Maize straw also has low bulk density because it consists of mainly loosened materials. The bulk densities of soybean straw and cotton stalks are larger because of their solid steam and compacted structure [26].

### 3. Crop residues for soil improvement

#### 3.1. Texture

Returning crop residues to soil can improve soil physical properties by increasing soil moisture content, decreasing bulk density, and increasing total porosity and aggregate stability [7,27,28]. Crop residue returning can increase soil moisture content by reducing surface runoff and direct evaporation, improving soil saturated water conductivity and water infiltration [1]. Lou et al. showed that straw coverage decreased the temperature of the topsoil (0–5 cm depth) and increased the soil moisture from 12.3% to 16.6% in 2008 and 2009, respectively, compared to the straw removal treatment in a 12-year maize field experiment [28]. Zhao and co-workers also demonstrated that the soil water content markedly increased by 19% after two-year straw incorporation compared with no straw treatment [7]. Nevertheless, the soil water content will be reduced at the beginning because of the adsorption of crop residue and microorganism. Therefore, watering in time is needed to accelerate the soil compaction, which make crop residue and soil more contacted.

Soil bulk density can be an indicator of the soil structure changes. Zhao et al. observed that the soil bulk density in the 0–20 cm layer decreased by 5.7% after 7 years of input of maize and wheat straw. In addition, straw return treatments decreased the soil bulk density in both the soil layers (0–20 cm, 20–40 cm) [29]. Xu et al. observed that maize straw return (4500 kg ha$^{-1}$) decreased the soil bulk density along the soil profile. Specifically, the soil bulk density decreased by 9.5% and 8.6% at the 0–20 cm soil layer and the 20–40 cm soil layer, respectively, in 2016–2017 growing season. They also found that the effect of straw return treatments on decreasing soil bulk density varied from different growth period of crops [30].

Soil total porosity is one of the basic physical properties of the soil and an index for the evaluation of soil fertility and productivity. The soil porosity increases when mixing crushed crop residues with the soil through deep plowing. When compared to no wheat straw treatment, wheat straw returning significantly (P < 0.05) increased the soil porosity in the 0–10 cm, 10–20 cm, and 20–30 cm soil layers by 5.06%, 5.21%, and 2.75% in 2019, respectively [31]. Another study conducted by Gao et al. showed that the total soil porosity increased by 23.0% at the physiological maturity stage under all summer maize stalks return treatment [32]. Zheng et al. also found that the total porosity of the soil increased by 21.7% with application of straw (4500 kg ha$^{-1}$ a$^{-1}$) in a five-year fixed-site field experiment conducted in a paddy field in Northeast China [33]. However, the high soil porosity leads to the soil and seeds cannot be in close contact, which affects the germination and growth of seeds. Therefore, timely watering and suppression are needed to make sure the soil compacted.

Agglomerates become larger and more stable with the crop residues inputting as the crop residues can replenish fresh organic matter to soil [34]. The proportion of soil large agglomerates and water-stabilized agglomerates reveal the sustainable capacity of soil [32]. The mean weight diameter (MWD) and geometric mean diameter (GMD) reflect not only the stability of aggregate but also soil’s potential for nutrient cycling. A 12-year field experiment conducted by Rigon et al. showed that absence of a spring cover crop resulted in lower MWD of water-stable aggregates [35]. In addition, Zhao and his coworkers found that the mass proportion of large macroaggregates (>2 mm) under wheat straw return treatment in the 0–10 cm increased by 6.7% in 2018. Besides, in 2019, the MWD and GMD values at 0–10 cm under wheat straw return treatment increased by 11.11% and 17.6%, respectively, relative to wheat straw removal treatment [31].

#### 3.2. pH and cation exchange capacity

Crop residues may have great influences on soil pH, especially those soils with low buffering capacity. Pan et al. conducted a 30-day incubation experiment to investigate the ameliorating effects on an acidic ultisol with four crop straw decayed products (SDPs), and the results showed that the soil pH increased by 55%-75% [36]. Nevertheless, the research results of Cao et al. showed that straw coverage with no-till and rotary tillage significantly reduced the soil pH from 7.7 to 7.4 and 7.2 [37]. In another study, it was observed that the application of crop residues to soil increased the pH of topsoil (0–10 cm) and subsoils, and the effects can persist over 26 months [38]. The changes in pH are related to the excess cation concentration, C and N cycles, types of crop residues and soil [6,38,39].

Crop residue management highly and significantly influences the cation exchange capacity (CEC) of soil. Accumulation of soil organic matter (SOM) in crop residues can produce more negative charges to
increase CEC [40,41]. Malobane et al. found that a 30% crop residue retention (based on total harvested fresh biomass) produced 11.3% and 27.32% higher CEC than that of 15% crop residue retention and crop residue removal, respectively, in a three-year field experiment with sweet sorghum [42]. Moreover, the topsoil (0–20 cm) CEC significantly increased by 9.39–21.59% compared with the control in a five-season wheat–guar rotation experiment when sole wheat residues were continuous incorporated [40]. CEC increased by 85% and 102% in the first and second cropping seasons by mulching residues [43]. Besides, the sandy Ultisol CEC increased by 0.72, 1.09, 0.99, and 1.05 cmol/kg after decayed products (SDPs) of peanut, pea, canola, and rice were applied [44]. The increase of CEC is mainly controlled by the accumulation of soil organic matter.

3.3. Organic carbon and soil nutrient

Decaying crop residues are considered as basic components in the nutrient cycle. Crop residue returning can increase the content of organic carbon, nitrogen, available phosphorus, and potassium in soils [7,45,46]. In addition, crop residue application into soil can prevent the loss of nutrients and improve essential nutrient availability [41,47,48].

Crop residues contain about 40% organic carbon, which can regulate soil properties and improve soil stability through the formation of large aggregates. The content of soil organic carbon increased by 52% and 50% with a treatment of 5% (w/w) raw garlic stalk in 2016 and 2017, respectively [46]. Crop residue returning can also reduce organic carbon loss [49].

Nitrogen is necessary for the formation of proteins, amino acids and nucleic acids. The nitrogen in crop residues can be transformed into NH$_4$$^+$ and NO$_3^-$ through mineralization and nitrification. Zhao et al. observed that straw and partial fertilizers incorporation significantly increased the soil available nitrogen at soil depths of 0–20 cm by averages of 64% [7]. However, crop residues have relatively high C/N ratio (60–100:1). Therefore, the increase of returned residues may improve nitrogen immobilization, which may in turn require additional nitrogen fertilizer application [50].

Phosphorus is an essential element for energy reactions and cell division. The phosphorus in crop residues can be decomposed into H$_3$PO$_4$ and HPO$_4^{2-}$ by microorganisms. Long-term crop straw incorporation (30 years) elevated soil available phosphorus in the 0–20 cm layer. At the same time, phosphorus use efficiency increased from 43% in 1983 to 72% in 2012 under mineral fertilization plus 3750 kg/ha wheat straw treatment [51].

Ionic potassium is easily released from crop residues. The input of crop residues contributes to the accumulation of potassium in soil [52]. Ali et al. noted that the content of available potassium increased by 4.4%, 6.5%, 3.8%, respectively, with raw garlic stalk application in 1%, 3%, 5% dosages [46]. In addition, the research results of Yadav et al. showed that retaining 90% (7.0 t) of soybean residues added 89.7 kg potassium in soil, and 232.2 kg potassium were added through 90% (13.8 t) wheat residues in 5 years [53].

3.4. Allelochemicals

Allelochemicals are mainly secondary metabolites bound up in crop residues, released by microbial decomposition as well as leaching in soil. These allelochemicals include low molecular weight compounds (such as sugars, inorganic ions, vitamins, nucleotides, amino acids and phenolics) and high molecular weight substances (polysaccharides, enzymes and other proteins). The allelochemicals released by crop residues have adverse or positive effects on the next crop. This is very closely related to target seed, specific allelochemicals and concentration [54–56]. Among allelochemicals, phenolic acids (PAs) are the most studied active substances and have been recognized as allelopathic substances. There is a common phenomenon that PAs inhibit seed germination and seedling growth during the decomposition of crop residue through allelopathy [57,58]. PAs can be generated in the decomposition of lignin catalyzed by the phenolase enzyme in fungi [59]. A study conducted by El-Mergawi showed that PAs caused great inhibition effects on germination of _Phalaris minor_. The inhibition effect was 21.5–75.7% and 48.7–100% at the concentrations of 10 mM and 20 mM, respectively [60]. Meanwhile, PAs have been shown to have antifungal effects, inhibitory effects on reducing growth of weed species and aid in the formation and stabilization of aggregates under appropriate concentrations [61–63].

The research results of Hou et al. showed that _B. cinerea_ mycelial growth and spore generation decreased by 86.18% and 69.10%, respectively, following 0.2 g/L PAs treatment [64]. Fertilization can reduce the content of phenolic acids in soil by promoting soil microbial activity. Above all, making full use of the active allelochemicals released by crop residues after returning to the soil and avoiding the adverse effects on the next crop have significant meaning in crop residues returning management.

3.5. Microbial activity

Soil microbial communities play an important role in soil ecosystem process and biogeochemical cycle of basic elements, such as nitrogen and carbon. Crop residue returning can increase the content of organic matter in soil and provide good environment for the growth and proliferation of microorganisms [39,65,66].
Sugarcane straw retention for 14 months can increase the diversity and abundance of fungi in 0–10 cm soil depth in the fallow ecosystem [66]. Additionally, Su et al. found that compared with wheat straw return, lower fungal community diversity and higher fungal pathogenic risk were observed in soil with corn straw return. Lower relative abundance of bacteria and fungi, but higher relative abundance of actinomycetes were observed in double-season straw return [12]. Ali et al. observed that garlic substrates increased the abundances and diversities of plant-beneficial microbes [46]. It was reported that long-term combinations of rice straw and inorganic fertilization had positive impacts on fungal diversity and population in paddy soils, and fungal functions were significantly changed [67]. Another long-term study (30 years) conducted by Zhao and Li showed that fungi and Gram-negative (Gm-) increased with straw input rates while all treatments did not change the abundances of total bacteria and Gram-positive (Gm+) in a summer maize-winter wheat cropping system in north-central China [68]. Soil microbial properties varied with the types of returned residues, the return rates and the soil conditions.

4. Crop residues for soil remediation

4.1. Heavy metals

Heavy metal pollution, such as cadmium (Cd), nickel (Ni), copper (Cu), arsenic (As), mercury (Hg), and lead (Pb) pollution, in soils have become a big issue. It causes reduction of food yield and presents threats to human health through food chains. Inhibitory effects of crop residue incorporation on the mobility and bioavailability of some heavy metals in soils have been reported [69]. A greenhouse pot experiment revealed that the rice straw reduced Ni bioavailability by 68% at 2% application rate [70]. Yang et al. observed lower Cd concentrations and distribution rates in rice gains than in the control samples after introducing of rapeseed residue into the Cd-contaminated paddy soils [71]. In the same way, the research results of Xu et al. showed that the Pb concentration in soil and shoots of maize was reduced by 13.5% and 58.2%, respectively, with 1% (w/w) rice straw treatment [72]. Two possible mechanisms are responsible for this reduced risk. One is the interactions between particulate organic matter from crop residues and metals. The other is the increase of microbial biomass and enzyme activity after crop residue application [73]

However, there are growing evidences that crop residue returning into soil can possibly enhance bioavailability of some metals, such as Cd, Hg, and As. For example, it has been reported that the amendment of rice straw into soils (1–5%, w/w) increased Cd accumulation in cabbages by 13.9–84.1% [74]. Shu et al. also found that composted straw treatments decreased methyl-Hg phytoavailability, however, dry straw treatments led to elevated methyl-Hg levels due to high levels of dissolved organic matter produced by rice straw decomposition [75]. Yang et al. reported that the total As concentrations increased by fourfold, from 482 µg/kg (control) to 1920 µg/kg (straw return) [76]. Four possible mechanisms are responsible for this situation: dissolution effect, complexation effect, methylation effect, and physiological effect [73]. The changes of metal mobility and bioavailability in soils after crop residue returning depend on multiple factors, including soil properties and the ways of straw application.

4.2. Organic pollutants

Soil organic pollution has become a common environmental issue. Cop residues dissolved organic matter plays an important role in affecting the migration and bioavailability of soil organic pollutants [77–79]. The calculated maximum sulfamethoxazole adsorption capacity of the purple paddied soils amended with canola straw-derived dissolved organic matter was 2.6 times greater than that of control [78]. Soil column experiment conducted by Schnitzler et al. showed that maize residues (10 t ha⁻¹) in the top 0–5 cm soil column layer decreased the mobility and bioavailability of benazolin and its metabolites [79]. The research results of Xiang et al. also showed the bioavailability of 2,2ʹ,4,4ʹ-tetabrominated diphenyl ether decreased 62.7%, 64.8% and 72.4% in carrot roots with 1%, 2% and 4% (w/w) maize straw amendment, respectively [80]. Similarly, 97% of phenanthrene concentration was removed with modified rice straw (be treated with NaOH solution) treatment in the phenanthrene-contaminated soil after 120 days through carbohydrate metabolism [81]. Bao et al. observed that polycyclic aromatic hydrocarbons (PAHs) decreased by 30.5–37.7% in a contaminated soil after 112 days of corn straw (6% w/w) incubation [82]. Crop residue input decreased the mobility of some organic pollutants through van der Waals forces, hydrophobic interactions, and electron donor–acceptor.

4.3. Pathogens

Crop residue returning was considered to increase pathogen amounts and promote diseases of crops. However, some studies have indicated that crop residue returning can increase the amounts of antagonistic microbes, and then control soil-borne plant diseases. Appropriate crop residue returning mode is an effective strategy to alleviate soil-borne pathogens [83,84]. Ali et al. reported that the addition of garlic substrate to the soil induced a certain level of beneficial microbial diversity that significantly contributed
to antagonizing pathogens and significantly decreased the disease incidence rate of cucumber *Fusarium wilt* [46]. Zhang et al. found that soil-borne pathogens decreased from 16.26% to 7.60% with sugarcane straw retention treatment [66]. As indicated in the results from the study conducted by Tang et al., wheat straw return increased the defense response to *Fusarium oxysporum f.sp. niveum* race 1 infection in watermelon monoculture through increasing the biosynthesis of lignin and auxin levels [85]. Besides, a three-season field experiment (from 2015 to 2017) showed that wheat straw mulching (5000 kg hm⁻²) decreased the total abundances of pathogenic fungi, such as *Fusarium*, *Alternaria*, and *Myrothecium* in wheat-soybean cropping system [83]. The key is to use disease-free and robust crop residue to the field to prevent the spread of germs and aggravate the disease of the next crop.

4.4. Salinity and alkalinity

Soil salinization and alkalinization severely constrain crop productivity in the world, especially in arid and semi-arid areas. Crop residue application has the potential to improve saline-alkali soils through water and salt management [86]. A three-year field experiment conducted by Zhang et al. showed that the salt leaching flux increased with different straw thickness (3 cm, 5 cm, 7 cm) treatment, and the results showed that the content of salt decreased by 3.07–36.82% in the 0–40 cm soil layer with compacted straw input of 7 cm [87]. Shao et al. also observed that Jerusalem artichoke residue incorporation reduced the soluble salt content of coastal saline soils by 91% and 92% in the 0–10 cm soil layer and in the 10–20 cm soil layer after 270 days with residue treatment (30 g), respectively [88]. In addition, the research results of Zhao et al. showed that maize straw layer (12 t ha⁻¹) buried at a depth of 40 cm and application of plastic mulch decreased the salt content by 51.3%, 42.2%, and 31.4% throughout the growth period of sunflower in 2011, 2012, and 2013, respectively [89]. Crop residues can increase the water storage capacity of soil, improve salt leaching efficiency, and reduce salt accumulation within the shallow soil depth [89–91].

5. Conclusion

Crop residues are carbon-rich materials that contain much nitrogen, phosphorus, potassium and microelements. Crop residue input is a sustainable way of improving soil quality without disturbing its biological balance. The decomposition of crop residues can increase the contents of organic carbon and available phosphorus, potassium in soils, which can provide nutrients for microorganisms and crops. In addition, soil moisture, aggregate stability, and porosity also can be improved. The negative effects of allelochemicals on crop growth can be adjusted by crop residue returning management. However, the results of crop residue effects on pH and heavy metals are inconsistent. Crop residues have inhibitory effects on some heavy metals under some conditions. Furthermore, crop residues have positive effects in reducing bioavailability of some soil organic pollutants, alleviating several soil-borne pathogens, and improving saline-alkali soils.

Reasonable crop residue returning mode is required to improve soil health. First, the addition of nutrients from organic crop residues should be synchronized with crops demand. Second, crop residue returning combined with partial nitrogen fertilizer, straw ripening agent, and lime can promote the decomposition of crop residues by improving the activities of soil microorganisms. Third, soil conditions, climate and crop residues quality may affect the decomposition process of crop residues and produce negative effects. Therefore, the systematic crop residue returning theory need to be established to ensure the soil health.

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