Bulletin of Environment, Pharmacology and Life Sciences
Bull. Env. Pharmacol. Life Sci., Vol 8 [1] December 2018 : 84-89
©2018 Academy for Environment and Life Sciences, India
Online ISSN 2277-1808
Journal's URL:http://www.bepls.com
CODEN: BEPLAD
Global Impact Factor 0.876
Universal Impact Factor 0.9804
NAAS Rating 4.95

REVIEW ARTICLE **OPEN ACCESS**

Crop residue management for improving soil fertility and enhancing crop production

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ABSTRACT
The cultural practices prevailing in the present agricultural scenario pose a very deleterious effect on soil fertility. The land has been used extensively over and over again; use of chemical fertilizers has been increased that has led to the deterioration of the land. The inherent capacity of the soil i.e., soil fertility, is now decreasing day-by-day. Soil fertility is the inherent capacity of the soil to sustain crop growth in the long-term. Soil fertility can be determined by the physical, chemical and biological processes that are interlinked to its soil organic matter content and its quality. Decrease in soil fertility is a major constraint towards low productivity. In recent years, concerns towards healthy food production and environmental quality have been increased. The increased emphasis on sustaining the fertility of soils has raised interest in maintenance and improvement of soil organic matter through appropriate land use and management practices. Crop residues are one of the important source of organic matter that are the left-over of the main produce and upon returning it to the soil for nutrient cycling helps to improve soil physical, chemical and biological properties. Its effective management in the field conserves the soil and its resources causing least damage to the environment.
Keywords: *Soil fertility, organic matter, crop residues, environment, sustainable agriculture*

Received 19.08.2018 Revised 26.09.2018 Accepted 12.11.2018

INTRODUCTION

The inherent ability of soil to satisfactorily sustain the crop growth and development in the long term is referred to as soil fertility. Soil fertility can be estimated by physical, chemical and biological processes that are intrinsically linked with the soil organic matter content and quality (Fig. 1). A decrease in the soil fertility is a major drawback towards the productivity, so investment in practices that lead to soil fertility enhancement is likely to generate large profits (30). Also, in the recent years, increased concerns towards healthy food production, environmental quality and increased emphasis on sustainable agriculture, have enhanced the interest in the maintenance and improvement of soil organic matter through appropriate management practices (21; 35). Crop residues, the products that are left after the procurement of the main produce, are an important source of organic matter which can be returned to the soil for nutrient recycling, thus improves the soil physical, chemical and biological properties (16). Over the globe, the total crop residue production is estimated to be 3.8 billion tons per year, of which 74% were from cereals, 8% from legumes, 3% from oil crops, 10% from sugar crops and 5% from tuber crops (17). Except carbon, crop residues contain all the mineral nutrients required by the crop but their content varies among crop genotypes depending on the soil fertility. To prevent the impoverishment of nutrients and organic carbon in the soil, these residues should be returned to the soil and spread uniformly over the entire field (5; 17). Prediction of the fact that how much nutrients are returned back to soil and how much is readily available to crops is quite difficult. This is a complex process that involves residue decomposition and nutrient release. The nature of the crop residue and its management significantly affect the amount of nutrients available as well as the content and quality of soil organic matter (16; 27).

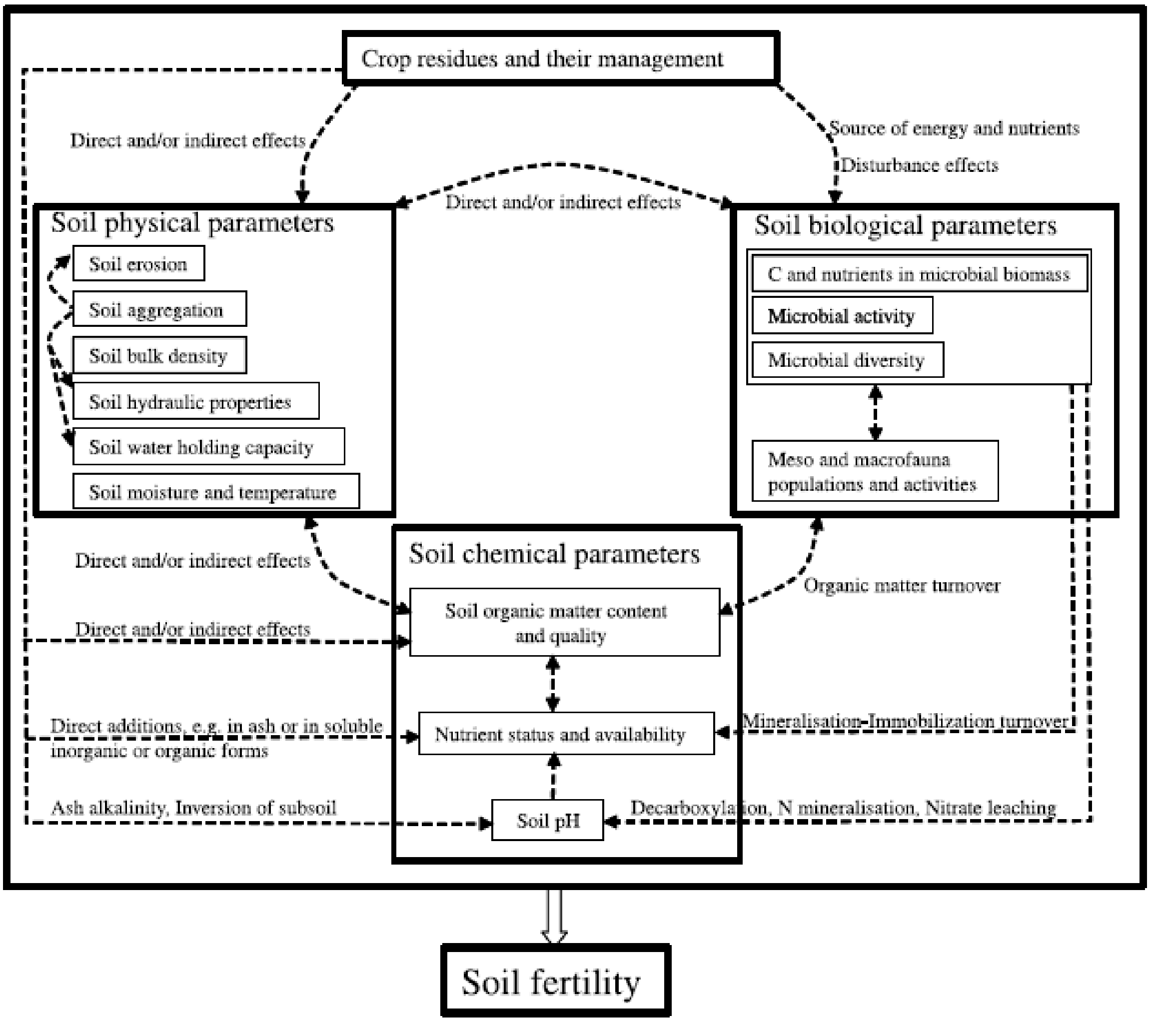

Fig. 1 Effects of crop residues and their management on physical, chemical and biological parameters of soil quality and overall soil fertility

Efficient management of crop residues in the field includes conservation of soil and its resources with minimum adverse effects on the environment (16; 21; 27). After harvesting of the crops, crop residues can be (1) left on the soil surface, (2) swathed and concentrated in windrows, (3) incorporated into soil, and/or (4) burnt prior to tillage or seedbed preparation. Crop residues that are partially or wholly removed from field can also be used as mulches, composts, industrial raw material, household fuel, bio-fuel generation and fodder for animals that gives excretory material in the form of dung thereby returning residues to the field as animal wastes (17; 28). Retaining of harvested crop residues in sufficient amounts on the soil surface together with no tillage, or its partial incorporation by minimal tillage (conservation tillage) decreases water and wind erosion (17).

Addition of residue to the soil in conventional or conservation tillage systems may also have positive effects on the level of soil organic matter and soil quality (1). However, conflicting reports on the rate and degree of organic matter accumulation associated with returning of crop residues to soil is mainly due to differences in climatic conditions, soil type, residue quality and the depth of sampling (1; 16). (9) have shown that among the 80% of the changes in soil carbon levels under cropping system, 20% were attributable due to residue management (stubble retained *Vs* burnt). Besides making the residues into smaller pieces and then mixing them in the soil (29) can mechanically breaks the soil aggregates which exposes the protected organic material to microbial decomposers, thus leading to faster losses of soil organic carbon (25).

Burning of the crop residues is usually a common practice done in an attempt to obtain a field that is easy to work on (i.e. improved tillage efficiency), to enhance the growth of the new crop, to reduce diseases as crop residues may sometimes serve as a host for pathogens, and to control weeds and insects (28) but repeated removal of residues by burning can cause significant environmental problems and loss in soil fertility due to land degradation.

This review mainly focus on the role of different crop residue management practices as well as the quantity and quality of crop residues in governing the chemical, physical, and biological parameters of soil quality. A better understanding of these aspects of soil fertility will help in maximizing the beneficial effects of crop residues on agricultural soils (such as minimizing soil degradation, increasing soil fertility through build-up of soil organic matter), and to minimize the negative effects (such as immobilization of nutrients, leaching and their run-off losses and erosion), thus contributing directly towards sustainable agricultural production systems.

Effects of Crop Residue Management on Soil Chemical properties

Soil organic matter

Soil organic matter content may vary depending on soil type and its management practices (1; 17). Continued losses of soil organic matter from agricultural soils have deteriorating effects on the global CO_2 balance and soil quality. Returning of crop residue to the soil, rather than its removal or burning, has been found in increasing the organic matter content of topsoil early, especially in the areas receiving annual rainfall >500 mm (1) whereas in tropical areas it requires more time for the increment of soil organic matter in the tropical areas (27). The reasons for these differences in the rate of soil carbon accumulation may be attributed to differences in the climatic conditions (e.g. dry and warm *Vs* wet and cold climate), edaphic factors, crop rotation systems, crop yield and differences in the amount of crop residues which are returned to the soil (1).

Soil pH

In governing the nutrient availability to plants, soil pH plays a major role. Increased use of nitrogenous fertilizer in cropping systems, including legume crops in crop rotation and continuous cultivation over many years have resulted in the development of acidic soils in many parts of the world (4; 32). pH of the soil can increase, decrease or remain unchanged due to the addition of plant materials to soil (31; 37). Due to residue decomposition, there is increase in pH for the initial one to two months and then it declines (3; 40; 18). The extent and direction of soil pH change depends on the concentration of excess of the base cations, organic anions, nitrogen in plant materials, initial pH level of the soil (31; 38), ammonification of plant residue, nitrification of ammonium and leaching of nitrate (37). The extent of change in soil pH also varies depending on rate of plant residue application and buffering capacity of the soil (13). Increases in soil pH by plant residue addition occur when the initial soil pH values were lower than those of plant residues or when the soil to be amended is acidic (31). In soils where pH values are greater than those of residues, the addition of plant materials can decrease the soil pH (31).

Some of the major causes of increase in soil pH upon addition of crop residues are (1) decarboxylation of organic anions that leads to consumption of protons and release of OH ions, (2) adsorption of organic molecules produced upon decomposition by Al and Fe hydrous oxides with release of OH ions, and (3) high concentration of excess base cations such as Ca, Mg, Na in plants (31; 36).

Nutrient status and availability in soil

Almost all the nutrients are present in crop residues except carbon that may not be readily available for crop use. Large amount of organically bound nutrients are present that have to undergo several biological processes (mineralization-immobilization turnover (MIT) before their availability to plants (23; 26). A conceptual model of carbon and nutrients in agro-ecosystems due to addition of crop residues in soil is depicted in Fig. 2. When the crop residues are returned to soil, they are readily colonized by a range of macro- and micro-organisms, which initiates the decomposition and mineralization process of crop residues and organic nutrients present in them. Growing microbial mass helps in assimilation of carbon and nutrients that are present in decomposing organic matter. As the time passes, the decomposing crop residues are converted into simple monomers that are further assimilated physically and chemically by microorganisms, stabilized in the soil and ultimately forming the soil organic matter (Fig. 2). The process of mineralization and immobilization in soil occur simultaneously, and their rate of availability from decomposing organic materials for plant uptake, leaching or volatilization depends on the net balance between these two processes by micro-organisms (20).

Some inorganic form of nutrients are present in crop residues that are soluble (e.g. K^+, SO_4^{2-}), or associated with organic constituents (e.g. amino- and protein-bound S and phosphate esters) (26; 23). Such nutrients are also released/ mineralized and immobilized in microbial biomass when returned in the form of crop residues to soil. Sometimes, soluble salts could also crystallize on the surface of residues when they absorb moisture but these can be washed off into soil with rainfall.

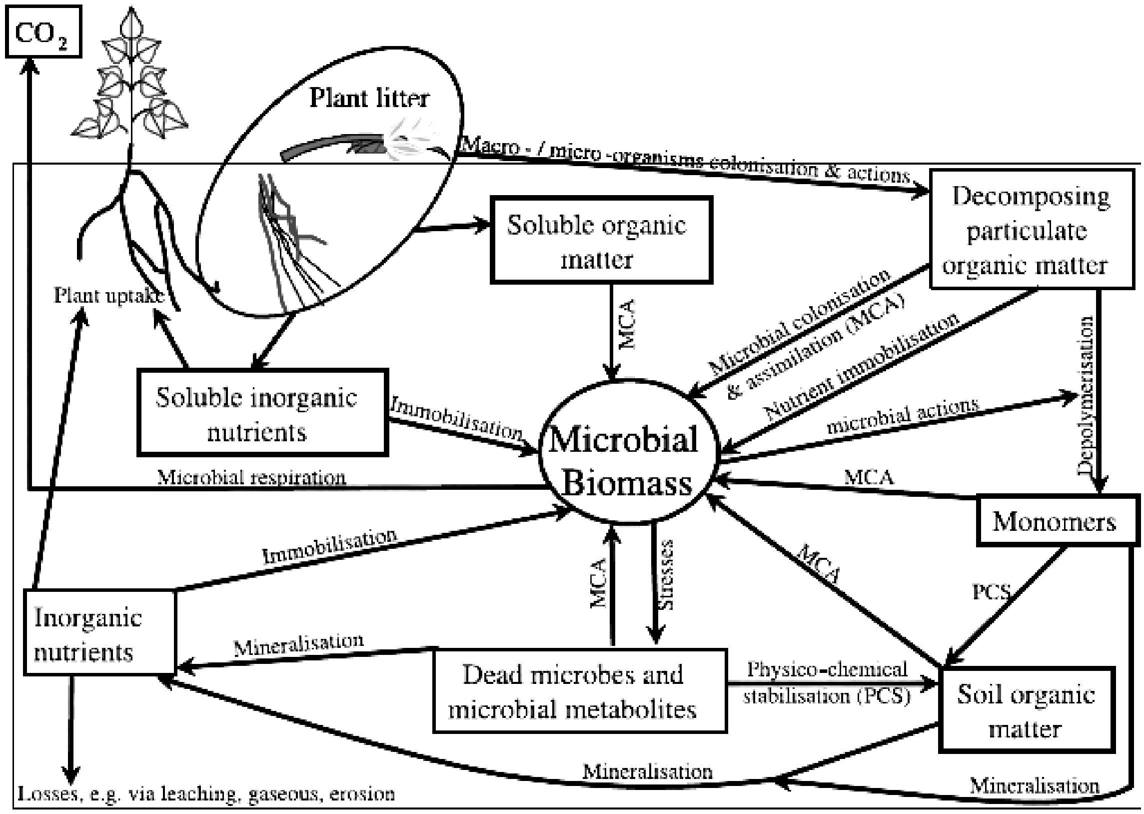

Figure 2 Conceptual flows of C and other nutrients in agro-ecosystems following addition of crop residues to soil

Effects of Crop Residue Management on Soil physical properties

Soil temperature

Significant changes in soil temperature can be caused by crop residue management by affecting radiant energy balance (14). Crop residue when applied as a cover on the soil surface, provides an insulation effect that varies depending on the amount and thickness of the cover (33). Further, bare soil i.e., soil without crop residue cover dries more rapidly than the mulched soil after precipitation or irrigation (6). The insulating properties of surface residue cover in wet conditions cause a decrease in temperature and temperature fluctuations as compared to bare soil (6; 13).

Burning plant residues can also affects significantly by changing the soil temperature. It depends on parameters such as thickness of the crop residue layer, fire duration and intensity, soil moisture, soil texture, soil mineralogy and soil organic matter content (12; 22). Extent of burning determines the changes in soil temperature (120–400 °C). Heat is mainly transferred to soil by thermal conductance, and its conductivity increases with increase in moisture content. It can be concluded that heating of dry soil results in greater rise in surface temperatures and less penetration of heat when compared to moist soil (22).

Soil moisture

Crop residues when placed on the soil surface (mulching) helps in reduction of water loss by evaporation (19). Thus, there is greater availability of soil water in the covered soil especially in years with there is low rainfall (8), hence very advantageous for rainfed agriculture in semiarid areas (2). Even in soils in colder regions, (11) higher availability of water can be obtained by covering the soil with crop residue.

Soil hydraulic conductivity and infiltration

For transporting water from the soil surface to deeper layers during rainfall or irrigation, high saturated hydraulic conductivity is important which decreases surface runoff/erosion and improves soil aeration in the upper part of the profile. Significantly higher hydraulic conductivity and surface infiltration rates were observed where residues were applied on the surface in no-till/minimum-tillage in comparison to where residues were burnt or removed (8; 34; 41). These effects of crop residues results in increased amount of soil organic matter content, macro- and total-porosity, proportion of micro-aggregates and aggregate stability, and decreased bulk density (10). Unsaturated hydraulic conductivity is important for the movement of water to the roots (15). In the case when crop residue was burnt, soil hydraulic properties is adversely affected by decrease in soil porosity (8) due to blockage of soil macropores by fine ash particles (34).

Soil bulk density and porosity

Continuous return of crop residues in soil results in increase of soil organic matter content that may decrease bulk density because of the dilution of the dense mineral fraction of the soil (24, 41). Tillage operations increased total porosity, but decreased number of macropores, stability and continuity compared with the soil with no tillage. Conventional tillage initially decreased bulk density by loosening the soil and temporarily forms macropores at the beginning, lower bulk density due to no till by the end of the growing season due to its positive impact on soil organic matter content and soil aggregation.

CONCLUSION

A large amount of fertilizer application can be saved by following the practice of residue management in the field. It helps in returning of the nutrients back into the soil. By retaining the crop residues on the soil surface not only reduces the surface runoff and soil erosion, but also improves the soil physical characteristics (such as hydraulic properties and soil aggregation) and helps in increasing the soil organic matter content, especially in the surface layer. Additionally, there is increase of soil microbial biomass and activity by the addition of crop residues which improves the nutrient-supplying capacity of soil and reduces nutrient losses.

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CITATION OF THIS ARTICLE

Girja Shanker Tewari, Navneet Pareek and Poonam Gautam. Crop residue management for improving soil fertility and enhancing crop production. Bull. Env. Pharmacol. Life Sci., Vol 8 [1] December 2018 : 84-89