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Efficient management of crop residue for optimum soil physical properties and their manipulations

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Abstract

Crop residues are important natural resources, and recycling of these residues improves the soil physical, chemical and biological properties. Crop residues are generally regarded as a waste, but when utilize properly, it improves the soil condition. There are several management options available, like burning, removal, incorporation, surface retention & mulching. Among this, most of the farmers resort to burning of residue to avoid interference with machinery while planting of next crop. Effects of incorporation, surface retention and mulching have been widely documented by researchers and found to be very effective in improving physical, chemical, and biological properties of soil. Residues decomposition product promote more aggregation, improves soil bulk density, total porosity, hydraulic properties, prevents surface sealing and crusting, allows more water to infiltrate by cutting down the runoff and soil loss. It maintain the soil thermal properties and soil moisture near surface Soil, thus enhances root and microbial activity and helps to achieve economic, ecological and socially sustainable agricultural production.

Keywords: crop residue, management options, soil physical properties

Introduction

Crop residues are often treated as something of little or no value (McKinney, 2004) [21] but crop residues have great potential to improve the physical, chemical, and biological status of soil (Lal, 2002) [13]. They are valuable resources when returned to soil (Wilhelm *et al*, 2007) [34]. Intensive agriculture, with unscientific management of land leads to mining of its essential nutrients and reduces its potential for crop production. In order to have a desired output, soil must be physically good enough to support optimum crop growth and to permit full utilization of its resources. For this, crop residue should be an integral part of farming system as it is one of the economical source to improve soil health. Crop residue mulch serves as a natural blanket to protect the soil surface against insolation and erosive impacts of raindrops and blowing wind (Blanco-Canqui, Humberto and Lal R 2009) [6]. It buffers the soil surface from excessive compaction, surface sealing, and crusting while reducing the breakdown and dispersion of soil aggregates. Used as surface mulch, crop residues improve soil structural properties by increasing soil organic matter concentration (Mandal *et al*, 2004) [20].

Total amount of crop residue produced in India is estimated at 350 x 106 kg yr^{-1}. Estimate shows that a 10 t ha^{-1} crop removes 730 kg NPK from the soil that is often not returned to the soils (Gupta R K, 2002) [9]. If this residue is not returned this may cause mining of soil for major nutrients leading to net negative balance and multi- nutrient deficiencies in crops. This is one of the reasons for the yield decline in the cropping system (Lal R and Kimble J M 2002) [13]. Thus, there are urgent needs to manage the residues of crops for sustainability and stability of the system. Management practices that minimally disturb the soil and produce, return, and leave more residue biomass on the soil surface (such as no-till) have the potential to decrease soil bulk density, increase porosity, and increase sorptivity in the soil over time. Also, systems that produce, return, and leave the largest amounts of crop residue in the soil have the highest potential for increased root activity, soil aggregation, and channels that can increase water infiltration.

Residue management option

Several management options available to farmers for the management of residues are burning, incorporation, surface retention and mulching, & removing the straw. Every management options have its advantages as well as disadvantages. The practice to be selected is based on the location, soil and situation (Mandal *et al*, 2004) [20].

Residue burning

As one of the low-priced practice of residue management traditionally residues are removed from the fields for feeding purpose of animals. Recently, with the advancement of mechanized harvesting, farmers have been burning in-situ large quantities of crop residues left in the field to facilitate timely planting of next crop, as crop residues interfere with tillage and seeding operations. This practice causes loss of nutrients and soil organic matter (SOM) leading to all kinds of environmental pollution. The advantages of the practice includes, Kills soil borne deleterious pests and pathogens, clear the land quickly of residues before the next crop is established, thus facilitating seed germination and establishment, and Controlling residue-borne diseases (Staniforth, A R 1982) [30], While disadvantage include, significant air pollution, Killing of beneficial soil insects and microorganisms, depriving soils of organic matter (Raison, R J 1979) [23].

Surface retention and mulching

Surface retention of residues from previous crop without incorporation helps in protecting the fertile surface soil against wind and water erosion. Residues decompose slowly on the surface, increases the organic carbon and total N in the surface soil, while protecting the soil from erosion and temperature fluctuations (Rasmussen, P E and Collins, H P 1991) [24]. Retention of residues on the surface increased soil NO3- concentration by 46%, N uptake by 29%, and yield by 37% compared to burning (Bacon, P E 1987). Disadvantage of this method is the machines failure due to large volume of residue remaining on the surface, thus affecting seeding of the following crop. It is generally fallowed where conservation tillage practices are prevalent.

Residue removal

Residue removal has adverse impact on aggregate stability as it reduces input of organic binding agents essential to formation and stability of aggregates. It also closes open-ended biochannels by raindrop impacts and reduces water infiltration rate, hydraulic conductivity, air permeability, and thereby increases runoff/soil erosion and transport of non-point source pollutants (e.g., sediment and chemicals). Residue removal accelerates evaporation, increases diurnal fluctuations in soil temperature, and reduces input of organic matter needed to improve the soils' ability to retain water.

Residue incorporation

Residue incorporation have been reported to be very efficient in improving physical properties of soil. Ploughing is the most efficient residue incorporation method (Ball B C and Robertson 1990) [2] (Christian D G and Bacon 1991) [7]. Unlike removal or burning, incorporation of straw increases soil organic matter, soil N, P and K contents. The major disadvantage of incorporation of cereal straw is the immobilization of inorganic N and N-deficiency, reducing the N uptake and yield of subsequent crops by about 40% (Bacon P E 1987) (Sidhu B S and Beri V 1989) [29]. This can be overcome by application of N @ 15-20 kg ha-1 as starter dose with straw incorporation which leads to increased yield compared to burning of straw (RWC-CIMMYT 2003) [26].

Residue management effects on soil properties

Long term residue incorporation in soil have numerous positive effects on physical properties of soil such as bulk density, aggregate stability, infiltration, hydraulic conductivity, soil moisture content, pore space, surface sealing and crusting, runoff and soil thermal properties etc.

Bulk density

Incorporation of crop residue into soil reduces the bulk density of soil. This is because of increase microbial activity and residue decomposition products that favours more aggregation and thus reduces bulk density. Beside, bulk density should decrease by dilution, as residue is lighter than mineral matter (Tim Shaver, 2010) [31].

Soil aggregation

Soil aggregation refers to the cementing or binding together of several primary soil particles into secondary units. Initially micro-aggregates are formed. Micro-agrregates together are cemented by various binding substances to form macro-agggreagtes (Elliott, 1986; Tisdall and Oades, 1982) [8, 32]. The binding substances include oxides and hydroxides of Fe and Al, organic substances directly from plants, decomposition products of crop residues, microbial cells, excretory products of microorganisms and gelatinous substances secreted by earthworms (Tim Shaver, 2010) [31]. With incorporation on crop residue, soil thermal and hydraulic conditions are improve facilitating more microbial activity and residue decomposition, resulting in the production of organic binding substances and excretory products of microorganisms that improve soil aggregation.

Structural stability

The larger the amount of crop residue returned to soil, the more the surface covered, the greater the protection of soil structure against natural and anthropogenic perturbations (Blanco-Canqui *et al*, 2006a) [4]. Soil is protected from the heavy impacts of raindrop and restrict surface sealing and runoff, allowing water to penetrate down the profile, insulates soil from high temperature and reduces soil organic matter loss, thus improve the structural stablity.

Surface sealing and crusting

Surface seals generally encountered in bare soil when raindrops strike the surface causing breakdown and dispersion of soil aggregates. During this course finer particles moved down along with percolating water and orient themselves that clog the pores near the soil surface. Surface sealing has adverse Impact on physical characteristics of soil that ultimately affects the soil productivity (Blanco-Canqui, Humberto and Lal R 2009) [6]. It reduces the saturated/unsaturated hydraulic conductivity, water infiltration/rate, and increasing runoff rate and amount. The higher density and lower hydraulic conductivity of crusts compared to the underlying soil layers limits seedling emergence, water, air, and heat fluxes, and increase soil erosion. Maintaining a complete and continuous cover with crop residue on the soil surface is essential to trim down formation of surface seals (Ruan *et al*, 2001) [25]. A soil surface protected with heavy crop residue does not seal or crust even in soils of high silt and low soil organic matter contents.

Total porosity

As the rate of crop residue removal increases the total porosity of soil tend to decrease. In Nigeria, Lal *et al*, (1980) [14] reported that mean total porosity was 0.49 $mm^3\ mm^{-3}$ under 0 and 2 Mg ha^{-1} of rice straw, 0.55 $mm^3\ mm^{-3}$ under 4 and 6 Mg $ha^{-1}$of straw, and 0.59 $mm^3\ mm^{-3}$ under 12 Mg ha^{-1}. Porosity is directly linked with bulk density because as bulk density decreases, porosity increases. As aggregates form and increase in size, inter-aggregate and intra-aggregate cavities form and increase. These cavities connect with other cavities creating conduits for fluid transport (Tim Shaver, 2010) [31].

Soil water content

Soil water content is one of the most sensitive parameters to crop residue management. Maintaining the soil surface covered with crop residue reduces evaporation rates and increases duration of first-stage drying (Mandal *et al*, 2004) [20]. Thus, residue-covered soils hold greater soil moisture within rooting zone of crop than soil without crop residue and maintain additional inches of water available for growing plants in late summer. Mulching with crop residues improves soil water storage by: (1) Increasing infiltration rate as total porosity is improved. (2) Decreasing runoff losses as residue retard surface sealing and crust formation, allowing more water to infiltrate. (3) Reducing evaporation and abrupt fluctuations in soil surface temperature, and thus helps in maintaining plant available water. (4) Increasing soil organic matter concentration, which increases water retention capacity of the soil (Blanco-Canqui *et al*, 2007a) [5]. Residue-derived soil organic matter interacts with soil matrix and increases the specific surface area of soil essential to adsorb and retain water molecules. Thus, soil water content and plant available water capacity increases with increaes in residue incorporation (Blanco-Canqui *et al*, 2007a) [5]. Depending on the amount of crop residues left on the soil surface, soil erosion can be reduced by up to 90% compared to an unprotected, intensively tilled field.

Soil thermal properties

Quantity of crop residue retained on the soil surface determines the soil temperature regime (Larney *et al*, 2003) [17]. Thus, any removal or addition of crop residues can rapidly change the soil temperature dynamics. Residue mulch insulates the soil surface from abrupt fluctuations in air temperature, but the amount of residue retained on the soil surface determines the degree of insulation (Kladivko, 1994) [12]. Mulch cover moderates temperature exchange and dynamics between the soil and the atmosphere (Sauer *et al*., 1996; Sharratt, 2002) [27, 28], in a way that mulched soils are normally cooler during the day and warmer during the night than unmulched soils.

Conclusion

Several residue management options are available to farmers for the management of residues viz. burning, incorporation, surface retention and mulching, & removing the straw. Burning however is effective with regard to facilitate timely planting of next crop as crop residues interfere with tillage and seeding operations, but this practice causes loss of nutrients and soil organic matter (SOM) leading to all kinds of environmental pollution. Another option is straw removal which generally reduces aggregate stability and accerlates runoff and soil loss. The most economical and that has been proved very effective by researchers is the incorporation and surface retention of straw. This helps in maintaining agronomic productivity by replenishing nutrients in the soil, increasing the soil organic matter (SOM) concentration, conserving soil water, reducing excessive evaporation, promoting biological activity, enhancing soil aggregation, strengthening nutrient cycling, reducing abrupt fluctuations in soil temperature, improving soil tilth (Wilhelm *et al*, 1986; Wilhelm *et al*., 2007) [33, 34]; improving water and air quality by reducing soil erosion and non-point source pollution, absorbing agricultural chemicals, filtering runoff, and buffering against the impact of air pollutants (Lindstrom, 1986; Mickelson *et al*., 2001) [18, 22]; and mitigating global climate change by sequestering SOC and off-setting emissions of CO2 and other greenhouse gases (GHGs) (Lal, 2008a) [16]. The recycling of crop residues has the great potential to return a considerable amount of plant nutrients to the soil. The yield stagnation consequent upon the declining soil organic carbon is a major threat to cropping system. Therefore it is a great challenge to the agriculturists to manage crop residues effectively and efficiently for enhancing sequestration of carbon, improving physical condition of soil and maintaining the sustainability of production. If crop residues are managed scientifically, then it can affirm the improvements in soil health and sustain productivity of cropping systems (Mandal *et al*, 2004) [20].

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