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STRATEGIES TO IMPROVE SOIL PHYSICAL PROPERTIES

P.R. Jadhvar, A. Pradhan, N. Dhumal, and S.A. Kochewad

ICAR- National Institute of Abiotic Stress Management, Malegaon, Baramati 413115

Corresponding author: prajaktajadhvar1996@gmail.com

ABSTRACT

Soil physical characteristics are vital for better crop growth, plant establishment and productivity. In recent decades, soil degradation occurred due to depletion in physical, chemical and biological qualities of soil, resulting in reduced crop productivity and yield. Hence, there is a need to improve soil physical properties such as structure, porosity, hydraulic conductivity, bulk density and strength. Strategies such as using organic amendments, reduced tillage, mulching, biochar, cropping system etc. can be adopted to keep the soil healthy.

INTRODUCTION

Soil is a natural body on land comprising of solids (minerals and organic matter), liquids and gases that serve as a natural medium for the growth of plants to support rooted plants. Soil holds water and essential nutrients for the growth and development of crop plants. For agriculture production, it is necessary to keep soil healthy and in good condition. Without healthy soil, farmers could not sustainably provide food, fodder, fuel, fibre, and many other things. Physical, chemical and biological properties characterize soil. The physical properties of soil are very important for sustainable production and use of soil. The amount of water, air and nutrients available for plant growth depends on soil's physical condition. The important plant growth-promoting factors such as root penetration, drainage, aeration, and retention of moisture and nutrients are all linked with the physical condition of the soil. Physical properties also influence the chemical and biological behaviour of soil. Physical properties depend upon the amount of organic matter, pore space, size, shape, arrangement and mineral composition of particles. For better agricultural production, the soil should have well-developed physical characteristics such as texture, structure, porosity, density (bulk and particle density), consistency, water-holding capacity and aggregate stability.

The physical characteristics of soil, such as water holding capacity, aeration and strength restrictions for root activity, directly impact soil productivity for crop production and development (Benjamin et al., 2003). The capacity of healthy soil to store and transfer air, water, nutrients and agrochemicals in ways that support optimal crop growth and minimal environmental damage (Reynolds et al., 2009). Hence, to support crop growth and production, sustain life and complete the increasing population's food demand, it is very necessary to keep the soil in healthy and good structural condition. To avoid structural deterioration and to maintain soil physical properties, it is essential to use different amendments suggested for soil improvement and to adopt the new technologies which sustain crop productivity while enriching the soil resource base.

NEED FOR IMPROVING SOIL PHYSICAL PROPERTIES

Physically poor soil drastically reduces plant growth and yield by soil compaction, surface crusting, erosion of the upper fertile layer, degradation of structure and unavailability of nutrients. Compact soil yields lower by 10-20% than healthy soil. Poor soil structure restricts root growth because of lower porosity, limits nutrient availability, and increases weed, insect pest, and disease infestation. Loss of nutrients and damage to soil physical properties occurs due to topsoil layer erosion, drastically reducing crop yield. Hence, there is a need to maintain and improve different soil physical parameters using various organic amendments.

Over the past few decades, the increasing population give rise to need for food, fibre and other raw materials to meet human requirements. It is vital to boost agricultural productivity to ensure a reliable food supply. This has led to a noticeable intensification of agriculture which accelerates the decomposition of organic matter and eventually degrades the physical properties of soil (Reynolds et al., 2002). Among many climatic and environmental factors, a significant decrease in crop yield was caused by different soil constraints such as hard soil pan, compactness, lower soil infiltration, lower porosity, degraded structure etc. therefore, it is mandatory to enhance soil health by improving its physical behaviour.

Better nutrient and water transport into the soil profile, higher nutrient and water retention and root growth can all be attributed to the soil with good structure, porosity, hydraulic conductivity, bulk density and strength. Such soil also yields better than degraded soil with weak physical qualities (Abdallah et al., 1998). Therefore, there is a need to increase the organic carbon levels of the soil in order to enhance its physical characteristics and fertility. A growing trend, for this reason, is the combined use of organic and inorganic fertilizers (Vanlauwe et al., 2004) and new emerging technologies such as zero tillage, conservation agriculture, mulching and biochar.

Soil physical properties are of significant importance in determining the abundance of microbes. Microbial diversity varies with soil texture. Sandy soil supports the fungal community, while clayey soils are conducive to the bacterial community. Larger pore size strongly correlates with the abundance of the fungal community. Organically managed soils with smaller pore sizes and higher water holding impede the fungal community by restricting hyphal growth. Higher clay and slit content were positively correlated with a higher microbial population (Li et al., 2018). In organic farming, due to organic matter application, higher soil moisture retention proliferates the microbial population.

ROLE OF SOIL PHYSICAL PROPERTIES IN AGRICULTURE

In agriculture, crop yield and production are mostly limited by the physical conditions of soil rather than its fertility and nutrient status. The different physical properties have different roles and impacts on soil and crop, which are very specific and interlinked to one another.

1) SOIL POROSITY is the ratio of pore volume to total soil volume. Simply these are the open spaces that can be found between soil particles. The pore spaces are necessary for soil aeration, water retention and nutrient flow. They also act as a harbour to microbes inside the soil.

2) BULK DENSITY is the ratio of the mass of oven-dry soil to the bulk soil volume, including pore spaces. Soil having BD >1.6 Mg m^{-3} has a lower capacity to absorb water and offer strong penetration resistance to plant roots into the soil, which will ultimately affect soil characteristics and plant growth.

3) WATER HOLDING CAPACITY is the maximum amount of water (at field capacity) a soil can retain against the force of gravity. It is important for optimizing crop production as its deficiency reduces growth, metabolism, nutrient transportation and crop yield.

4) AGGREGATE STABILITY is the measure of soil particles that bind together and resist breaking apart when exposed to external forces (erosion, shrinking, swelling). Well-aggregated soil provides a good medium for nutrients and water transport which plants can absorb effectively.

5) WELL-DEVELOPED STRUCTURE means soil with a good network of pore spaces that allow free movement of air, water and nutrients, proper water drainage, and unrestricted root growth. Such soil allows better plant growth and supplies every essential factor to the plant.

6) SOIL TEXTURE is the composition or percentage of soil particles, i.e. sand, silt and clay. It is the property which influences the drainage of water through a saturated soil, the amount of water the soil can hold and also shows soil fertility status.

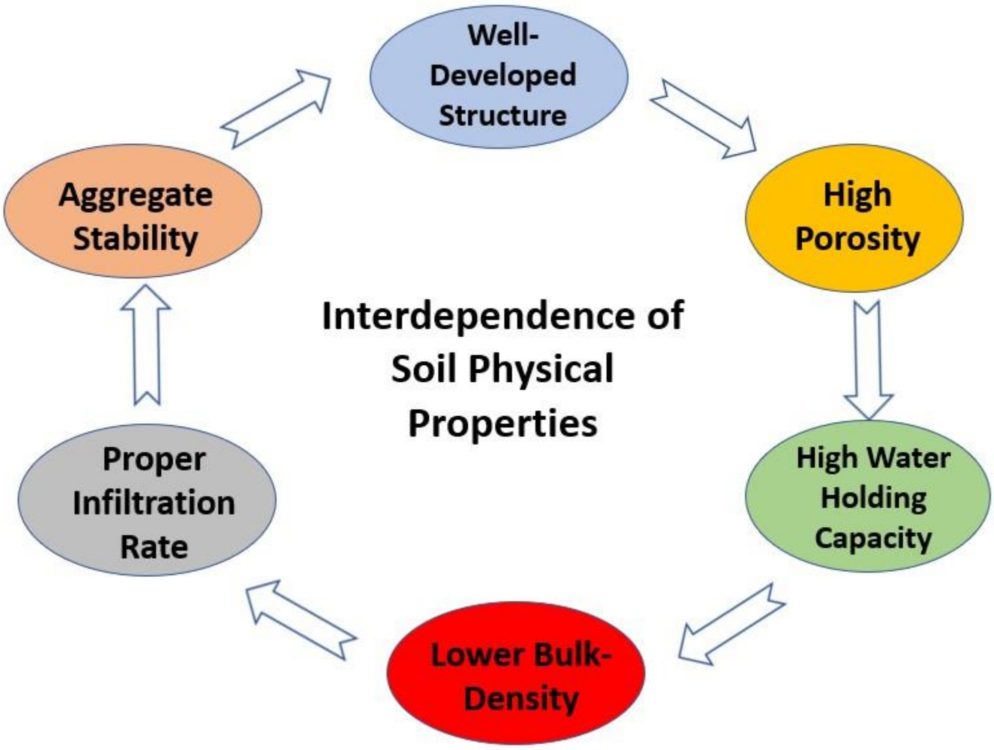

Fig 1. Components of soil physical properties

STRATEGIES TO IMPROVE SOIL PHYSICAL PROPERTIES:

A) TILLAGE APPROACHES

Modern tillage practices such as reduced tillage, minimum tillage, zero tillage or no tillage, row zone tillage, plough plant tillage, Stubble mulch tillage etc., are being populated worldwide due to their different potential benefits for the conservation of soil as well as water. Reducing tillage aims to minimize the tillage operations to minimum necessary levels for ensuring good seed bed, rapid seed germination (Minimum tillage), leaving crop residues on the surface during fallow periods (stubble mulch tillage), planting crops in the residues of the previous crop without any prior soil tillage (zero tillage) (Kumar et al., 2016). No-tillage cropping systems followed by fallow land can return more crop residues, decrease bulk density, increase total and effective porosity, and enhance soil aggregation compared to crop+fallow land (Shaver et al., 2002).

B) OPTIMUM USE OF MANURES AND COMPOST

Applying organic amendments can reverse the soil degradation process by improving the soil physical properties like soil aggregation and its stability, water holding capacity, hydraulic conductivity, bulk density and water infiltration rate (Franzluebbers, 2002). Wheat (*Triticum aestivum*) straw, composted sugarcane bagasse residue, and farmyard manure increased aggregate stability, infiltration rate and decreased soil bulk density one year after its addition to the soil and the effectiveness of all these organic materials on improving soil physical properties was similar (Barzegar et al., 2002). Poultry manure is also one of the best organic materials, which is a rich source of nutrients and improves soil conditions. The addition of poultry manure decreases bulk density, and increases organic matter content, total porosity, water infiltration and hydraulic conductivity (Obi et al., 1995).

Fig 2. Decomposed Goat Manure

C) CROP RESIDUES MANAGEMENT

After harvesting and threshing, some plant parts left over in the field are known as crop residues. Out of around 500-550 million tons of crop residues produced in India annually (MoA, 2012), a large proportion is burnt in the field to clear leftover straw and stubbles. Instead of burning or removing residues from the field, it is more adventitious to convert those waste into useful product or retention of residues on the surface of the soil to conserve soil and water. Residue retention on the surface avoids the splash impact of raindrops on the soil; hence, the problems associated with it, such as compaction, reduction in pore proportion, and lower infiltration, can be solved. Incorporating crop residues in the soil reduced bulk density, soil compaction (Bellakki et al., 1998), increased infiltration rate, WHC, microbial population and soil fertility (Neelam et al., 2017). It is said that the ills of conventional agriculture can be reduced by crop residues (Das et al., 2020) and improve the soil condition for adaptation to climate risk (Thierfelder et al., 2018). Maintaining soil residue cover increases organic matter, makes the soil more porous, improves soil structure, conserves soil moisture, and protects the soil from physical degradation (Salahin et al., 2017). Soil bulk density indicates the soil's ability to function for structural support, water and solute movement (Tang et al., 2013). Residue retention significantly decreases soil BD in the topsoil surface as it makes the soil more porous and increases its carbon.

D) MULCHING

Mulch may be defined as a coating material which may be organic or synthetic and spread over the soil surface (Kasirajan and Ngouajio, 2012). It is an important agronomic practice that acts as a barrier to evaporation and soil erosion from water by reducing raindrop impact and thereby protecting soil structure. It includes residue mulch (straw stover, sawdust, grass clippings, sugarcane trash etc.), organic matter mulch (compost, FYM, sludge) and synthetic mulch (polyethene film, polyester sheet, latex) (Singh and Agrawal, 2020). Soil moisture storage increases after the application of straw mulch (Ji and Unger, 2001). However, mulching effects on bulk density were variable.

In some cases, high bulk density has been observed compared to conventional tillage (Bottenberg et al., 1999), and other low bulk densities have been reported (Oliveira and Merwin, 2001). This may be due to differences in soil type, type of mulch material used and management practices followed. Oliveira and Merwin (2001) also reported increased soil porosity due to mulch application which is important for crop and root growth since it has a direct impact on soil aeration and indirect impact on soil compaction. In addition, increased mulch rate increases aggregate stability, soil porosity, available water capacity and moisture content at field moisture capacity (Mulumba and Lal, 2008).

E) BIOCHAR

Biochar is carbon-rich, fine-grained, a porous substance produced under oxygen-limiting conditions at a temperature between 350 to 7000C. It is very important for improving degraded soil and soil physical properties such as bulk density, water holding capacity, porosity, soil permeability and particle size distribution. Biochar poses many benefits to the environment agriculture and economy in the long run, so it is highly recommended to incorporate it into agriculture practices. (Rehman et al., 2017). It is highly porous, hence increasing soil porosity and decreasing bulk density by increasing pore volume. Kolb (2007) observed that biochar is beneficial to soil and experimentally proved that it is linked to improved soil structure and aeration in fine-textured soils. Mankasingh et al. (2011) evaluated biochar application in a tropical agricultural region to investigate biochar's potential to alter soil properties. Biochar was applied at different rates, and observed that there was a steady decrease in soil bulk density from 0.99 to 0.89 Mg m-3 as the rate of biochar get increased.

Fig. Prepared Biochar from field residues

It was found that soil aggregation capacity improved by the secretion of polysaccharides from microorganisms. Biochar application protects microorganisms from predators and desiccation, thereby increasing soil aggregation (Angers et al., 1993). It was determined that using biochar boosted 97% of soil's available water content and 56% of saturated water content (Uzoma et al., 2011).

F) APPROPRIATE CROPPING SYSTEM

Appropriate cropping systems and improvement in soil physical properties are related to an increase in organic matter content in the soil. The roots of growing plants show both action of aggregate formation and breakdown. Aggregates typically degrade during cultivation as farmers follow deep tillage and conventional agricultural practices. In annual crops like wheat and maize, when grown on soil, the stability of soil aggregates frequently declines (Angers et al., 1999). A cropping system and soil management that can accumulate plant residues can enhance soil quality by boosting soil aggregate stability, shear strength and resistance to splash detachment. Instead of continuous corn or wheat cropping system, a rotation of corn-wheat-red clover increased aggregate stability by 23-40% (Rachman et al., 2003). Linh et al. (2016)

demonstrated after experimenting with 25 cropping seasons (8 yrs) that lower soil compaction, lower degradation and enhanced soil aggregate stability were found under rice and upland crop rotations with temporary beds as compared with long-term intensive rice mono cultivation. The cropping system provides canopy protection during the fallow period. According to Six et al. (2004), soil aggregate stability is mostly due to the presence of organic matter and binding agents produced by microorganisms, root activities, soil fauna and environmental conditions.

CONCLUSION

Deterioration of soil physical properties and health is the major problem in boosting crop productivity and yield. Decrease in crop yield due to soil compaction, hard soil pan, lower porosity and infiltration rate, and loss of soil nutrients due to deteriorated structure can be minimized by improving soil physical properties through various strategies. Increased organic matter increases soil organic carbon level, which improves soil water retention capacity, structure and fertility. Reduced tillage improves soil aggregation and infiltration rate. Optimum use of manure and compost also increases organic matter, which is a key component in soil quality. Crop residue management and mulching reduce soil erosion by improving infiltration rate and water loss through soil evaporation.

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