EFFECT OF COMPACTION ON SOIL BULK DENSITY: A REVIEW

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Abstract
Compaction of agricultural soil is a major concern for many agricultural soil scientists and farmers. Soil compaction, due to heavy field traffic, has resulted in the uneasy flow of water into the soil for crop use which has led to yield reduction of most agronomic crops throughout the world. Soil compaction is a physical form of soil degradation that alters soil structure, limits water and air infiltration, and thus reduces root penetration in the soil. The review shows the tentative approach in the understanding and quantification of the effects of soil compaction. We found the following major points: (1) Exposure of the soil to vehicular traffic load, soil water contents, soil texture and structure, and soil organic matter are the three main factors which determine the degree of compactness of that soil. (2) Soil compaction has direct effects on soil physical properties such as bulk density, strength, and porosity; therefore, these parameters can be used to quantify soil compactness. (3) Modified soil physical properties due to soil compaction can alter elements mobility and change nitrogen and carbon cycles in favour of more emissions of greenhouse gases under wet conditions. (4) Severe soil compaction induces root deformation, stunted shoot growth, late germination, low germination rate, and high mortality rate.

1.0 INTRODUCTION

Soil has been described to be complex mixtures of minerals, water, air, organic matter, and countless organisms that are the decaying remains of once-living things. It forms the surface of land thus it is said to be the skin of the earth (NRCS, 2006). Soil is known to support plant life and is vital to life on earth. The unconsolidated mineral and organic matter on the surface of the earth has been subjected to several genetic and environmental factors such as climate (including water and temperature effects), macro and microorganisms, conditioned by relief, and weather action on parent material over time (NRCS, 2006)

Soil bulk density (ρ_b) is defined as the ratio of dry soil mass to bulk soil volume (including pore spaces) The SI unit for density is mega grams per cubic meter (Mgm^{-3}), which is numerically equivalent to grams per cubic centimetre (McKenzie, 2002). It is also an indicator of soil compaction. DOA (1970) stated that bulk density (ρ_b) is calculated as the dry weight of soil divided by its volume. This volume includes the volume of soil particles and pores among soil particles. Just as soil is a combination of soil minerals, organic matter, and air- or water-filled pores, so soil bulk density is a weighted average of the densities of these components. According to McKenzie, (2002). Thus soil bulk density is generally expressed as

$$\rho_b = f_a\rho_a + f_p\rho_p + f_o\rho_o + \cdots \ldots\ldots\ldots\ldots.. + f_n\rho_n \qquad 1$$

Where:

f =is the volume fraction of a component,

a = is the air pore space

p = is the soil mineral particles

o = is the organic matter while

n = is the infinite value.

High bulk density is an indicator of low soil porosity and soil compaction. It may cause restrictions to root growth, and poor movement of air and water through the soil, bulk density is primarily a function of relative pore space and OM content (Arshad, 1996)

$$\%\text{ pore space} = (1 - \frac{\rho_b}{\rho_p}) \times 100 \qquad 2$$

ρ_b = Bulk density

ρ_p = Particle density

Bulk density reflects the soil's ability to function for structural support, water and solute movement, and soil aeration (Arshad, 1996). Bulk densities in table 1 thresholds indicate impaired function. Conversion between the weight and volume of the soil is also determined using soil bulk density.

Table 1: General relationship of soil bulk density to root growth based on soil texture

Soil Texture	Ideal bulk densities for plant growth (g/cm^3)	Bulk densities that restrict root growth (g/cm^3)
Sandy	<1.60	>1.80
Silty	<1.40	>1.65
Clayey	<1.10	>1.47

Table 1 shows the relationship of three different types of soils (sandy, silty, and clayey soils) with relation to their bulk densities ideal for plant growth and bulk densities that restrict the proper development of the root systems. The sandy soil shows its bulk density at about 1.60 g/cm^3 which is much ideal for plant growth, but its bulk density above 1.80 g/cm^3 hinders the development of the root systems. Silty soils also show that its bulk density at 1.40 g/cm^3 is favourable for plant growth and its bulk density at 1.65 g/cm^3 is also not favourable for root growth. And clayey soils show that at bulk density even at 1.10 g/cm^3 is ideal for plant growth, but bulk densities at 1.47 g/cm^3bulk density is not favourable for root growth development.

1.1 DETERMINATION OF SOIL BULK DENSITY

There are basically four methods used in determining soil bulk density (Zhao, 2010):

- Core method
- Excavation method
- Clod method
- Radiation method

A. Core method

The core sampler is pushed or driven into the soil to the desired depth and then removed. Many samplers are available which are provided with a metal casing to hold the core and permit easy removal and handling of the sample during weighing, wetting and drying. If the soil sampler is assumed to be full its volume may be used as the volume of soil.The intact core is removed, dried in an oven at 105°C, and weighed.

A larger diameter core diminishes all disadvantages of small sampling area, compression of soilinside the core and stones present except when rocks are large but closely spaced.

Plate 1: A three inch diameter ring is hammered into the soil to collect bulk density samples

Source: (Arshad, 1996)

Advantages - It's fairly quick and it's easy to use

- Does not require expensive instrumentation or skill labour
- The coring tool does not rust, and
- It is also light weight and requires no lubrication
- The cutting head can also be removed by hand and also removing samples from tube is quick and simple

Disadvantages - compression of soil inside the core

- Presence of coarse particles (may be skeletal material) inside the core and small sampling volume (Monoj, 2013)

- Only small sampling area of core can be covered, the coring tool does not function well in muddy soils or over irrigated agricultural land and also stony soils. (Yoav, 2006).

A larger diameter core diminishes all these disadvantages, except when rocks are large but closely spaced.

B. Excavation method

In this method, level soil surface is dug to a desired depth. A hole is lined with a plastic, then it is filled with a measured volume of water. Excavated soil is then dried and weighed. The major advantage of excavation method is that it can be done in stony or gravelly soils. While it's major disadvantages are that water gets heavy to lug around and excavated soil is no longer undisturbed. If done properly, this method will usually give you more accurate numbers than core methods (Blake, 1986).

Plate 2: Excavated soil, ready to be oven dried.

Source: (McKenzie*et al*, 2002)

Advantages - It gives more accurate results in deeper soil depths, larger sample sizes can be fetched and it can also be done in stony or gravelly soils

Disadvantages - Water gets heavy to lug around

Also there are problems associated with the use of plastic, weather conditions, and transport of large amounts of water.

If done properly, this method will usually give you more accurate numbers than core methods.

C. Clod method

The bulk density of clods, or coarse peds, is calculated from their mass and volume (Blake,*et al.,* 1986).The volume is determined by coating the clod with a water-repellent substance and by weighing it first in air, then again while immersed in a liquid of known density, making use of Archimedes' principle.

Advantages - This method can be used only if other methods are not visible.

Disadvantages - Giving higher bulk density values than do other methods and it does not take the inter-clod spaces into account

D. Radiation methods

The radiation method involves measurement of radiation transmitted through the soil using a detector mostly in the laboratory. In the field, the backscatter of rays from the soil can be recorded by a detector (Manoj k. Shukla, 2014).

Advantages -it is quicker to use, especially where measurement at depth are required.

- It also has added advantages of being non-destructive and therefore allows repeated measurement at the same location.

Disadvantages - It is more expensive and requires skilled labour and careful adherence to the nuclear safety protocols.

2.0 QUANTIFYING THE EFFECTS OF THE SOIL BULK DENSITY

To show the peculiarities of soil compaction, physical parameters such as the bulk density and porosity, soil strength, water infiltration rate and reduction of aeration have been used. Indeed, under natural conditions, due to steady state aggregation and biological processes, the soil contains large proportions of macro pores. Macro pores are relatively more affected during the soil compaction than the micro pores.

2.1 Bulk density and porosity

Direct methods for determining bulk density and water content involve the sampling of a known volume of soil which is then weighed in both wet and dry states (Hakasson and Lipiee, 2000). Typical resistant indicators used now are days are highly precise, as the soil density measures up to the soil depth of 20cm. while for deep stratum, the stress state transducers with six earth pressure gauges that measure three dimensional stresses can be useful (Eguchi and Muro, 2007). For an accurate measurement of the effects of the soil compaction on all types of the soil, the soil bulk density alone is not adequate but other soil properties such as the soil strength, soil aeration, and soil moisture should be measured (Lipiee and Hatano, 2003). It was reported that an increase in contact pressure of 100 kilo Pascal (kpa) caused a decrease of 5.7% in the soil porosity at 10-15 cm depth after 24 passes in the sandy humus rich forest soil (Sakai et al. 2008).

2.2 Soil strength

The soil strength is measured by a penetrometer and further more cone penetrometer is widely employed to measure the soil strength in terms of cone resistance in mega Pascal (Uzowiez and Lipiee 2009).

3.3 Water infiltration rate

Soil water infiltration rate can also be used to monitor the soil compaction status, because the soil compaction reduces the total porosity of the soil (Silva *et al*. 2008). These mainly involves the number of macro pores, as water infiltrates faster in non-compacted soil than in a massively compacted soil of the same type (Hamza and Anderson 2003). These are not directly related to the changes in porosity but rather to the changes in both the number of macro pores and in connectivity between macro pores. Such changes in the ratio of the convoluted pathway of the fluid diffusion through porous media can influence the soil electrical conductivity (Selaji*et al*. 2010).

3.4 Reduction of aeration

Air permeability varies largely according to the soil physical properties for the same level of compaction, while the measurement of oxygen diffusion rate (ODR) by electrode needs a lot of care. Redox potential measurements can be a good tool to characterize the compacted soils as these measurements can be carried out in situ for the long periods, but this method is only applicable to the very wet soils close to or at saturation (Feder*et al*. 2005; Lipiee and Hatano 2003; Nawaz 2010). Among different method discussed, the soil bulk density and the soil strength are more commonly employed to quantify the soil compaction but the use of other indicators like water infiltration rate, oxygen diffusion rate (ODR), redox potential, etc. in combination with them can largely increase our understanding and results precisions. Sensors have also been developed to detect the location and depth of the hard pans in real time that are equipped with four horizontal operating penetrometers, for on-the-go sensing and mapping of the location and intensity of hard pan (Loghavi and Khadem 2006). Sensory systems have been also developed to measure the soil compaction that has already been reviewed (Hemmat and Adamchuk, 2008).

4.0 Effects of compaction on the soil chemical properties and biogeochemical cycles

4.0.1 Reductive conditions

Chemical properties are influenced by modified soil physical properties due to soil compaction such as the reduced water infiltration rate and reduced soil air permeability (Nawaz *et* al., 2013). The soil compaction causes decrease in oxygen diffusion and can lead to anoxic conditions in compacted soils if consumption of oxygen is faster than diffusion (Schnurr–putz*et al*.2006).Selective extraction techniques using citrate– bicarbonate and citrate–bicarbonate–

dithionite showed that the soil compaction under forest resulted in an increase of readily extractable iron oxides after two years, before mineralogical transformations were detectable by XRD (Nawaz *et* al., 2013).

4.2 Carbon and nitrogen cycles

In a laboratory experiment, when silt loam (acid forest soil) was compacted artificially to a bulk density of 1.5 from 1.1 Mg/m^3, a significant reduction in the carbon mineralization and net nitrification rates was observed after 9 months (Tan and Chang, 2007). The soil compaction, directly, results in the lower efflux of carbon dioxide CO_2 from compacted soils (Silveira*et al.* 2010).

4.3 Environmental impacts of the soil compaction

The soil compaction reduces the available Nitrogen (Tan *et al.,* 2008) and efficiency of Nitrogen use by the crops decreases, which can increase the fertilizer requirements.

Anaerobic conditions in the soil due to the soil compaction can result in reduced decomposition of pesticide and ultimately increased leaching of pesticide in groundwater and aquifers (Alletto *et al*. 2010). Similarly, decreased hydraulic conductivities can result in slow downward movement of water and, ultimately, more nitrate contents in ground waters.

If the soil compaction is carried out in steep slopes, this can result in increased runoff and ultimately increase soil erosion and sediment transport which could be a serious problem for the landscape. Increased runoff in slurry applied fields can result in the entrance of slurry in surface waters and ultimate threat to the aquatic life as degradation of slurry can reduce the oxygen levels in surface waters (Nawaz*et al*., 2013). However in some soils (sandy soils), soil compaction increases the soil strength, erodibility, and consequently the soil erosion for the same amount of runoff is reduced.

4.4 Effect of the soil compaction on plants

Overall effect of the soil compaction on the plant yield is negative (Ishaq *et al*. 2001; Saqib *et al.* 2004). If a soil is already suffering from other types of degradation such as the salinity, drastic effects of the soil compaction on the plant growth and crop yield are reported to be doubled (Saqib *et al*. 2004).

4.5 Roots

Generally, compaction results in a decrease in the root length, root penetration, and rooting depth (Riley 2005). Top soil compaction is a more limiting factor for the root growth than the subsoil compaction. Botta *et al*. (2006) and Saqib*et al*, (2004) found that the compaction of a sandy clay loam soil to a bulk density of 1.65 from 1.21 Mg/m^3 reduced root length density of wheat plants while the presence of salinity (15 dS/m) was more drastic than the soil compaction alone. In the same experiment, they observed greater reductions in potassium K^+ concentrations and the potassium and sodium K^+/Na^+ ratio in leaves due to interaction of salinity and compaction.

Conclusions

Since soil bulk density is a reflection of being an important function of the soil, there is need for the soil to provide good structural support, water and solute movement, and aeration for the plants. The review paper tends to show how important determination soil bulk density is, as the knowledge of various soil bulk densities helps the farmer have good idea of an ideal soil bulk density that will boost plant growth and development. And also knowledge of unfavourable soil bulk densities that restrict the proper development of the root systems and the plant in general.

The review shows the various methods of soil bulk density determination. Thus, core sampling method is generally taken to be the standard method, but it is somewhat unsatisfactory for stony or non-coherent samples out of the three other methods (clod, radiation and excavation methods). But it shows that the core method is the most favourable and flexible due to its affordability, running cost, easy maintenance and overall accuracy during field operations.

The review tends to show that knowledge of the effect of compaction on the soil chemical properties and biogeochemical cycles leads reduction of fertilizer requirement by the farmer. Also knowledge of the anaerobic conditions in the soil due to the soil compaction can help reduce leaching of pesticide into ground water and aquifers.

The review also shows more understanding and achievement of results precisions when quantifying soil bulk density if physical parameters are used.

Compaction of the soil cannot be avoided as it occurs due to different factors beyond control, but it effects can only be limited by adopting healthy farming practices.

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