Mini Review Paper

A Review of Soil Compaction- Concerns, Causes and Alleviation

Abstract

Soil compaction is an important soil management issue of the sustainable agriculture throughout the world. High weight of tractors and farm machineries increases the concern about the soil compaction. This review act as a guide for farm persons on the negative impact of soil compaction on crops causes and soil management practices and methods for alleviation of compaction with decreasing the risk of more extensive compaction damage in the future. Compaction changes many soil properties and negative effects are related to a decrease in permeability to air and water in root zone of crops. This results into decreased crop production and increased draft of tillage operations. The major causes of the soil compaction are use of heavy machinery traffic, performing same farm operations on the field, poor crop diversification and time restrictions in the crop cycle. To correct soil compaction problem, first tactile method is to avoid or limit farm operations that causes the compaction. Major methods to alleviate compaction include optimized tilling of soil, incorporating priming crops in crop rotation, subsoiling and controlled traffic farming. Monitoring of soil conditions constantly and wise use of farm machinery is the most viable approach to tackle the soil compaction.

Keywords: Soil compaction, controlled traffic farming, subsoiling, heavy machinery, alleviate soil compaction.

Introduction

Soil compaction has become a more of a problem in recent years due to increased use of heavy machines and poor variation in cropping culture. It occurs when soil particle are pressed together resulting in elimination of pore space in soil profile. In scientific terms, soil compaction is physical consolidation of soil by applied force that destroy soil structure, decreased porosity, limited water, air and nutrient availability and increased resistance to root penetration that often result in reduced crop yield. Soil consists of soil particle, pore space and organic material. Pore space holds air and water due to capillary action of water. When somehow pore space is decreased by loading condition, it cannot recover it on its own, as soil is not an elastic material. Soil structure is permanently deformed. This leads to poor availability of moisture and air for growing plant. It then becomes a problem. Reduced pore space also results in lower percolation of water and hence result in water logging condition. This worsen the problem. Dry soil is less susceptible to compaction due to high friction between soil particles. There is a strong negative effect of wet soil compaction on soil physical properties (Mada, Ibrahim & Hussaini, 2013). Moisture lubricates the soil particle flow. This results into close fitting of soil particles in soil profile. The depth of the soil compaction varies from 10-60 cm (Flowers and Lal, 1998) but it is more obvious on top soil (around 10 cm).

Soils consisting of particles of about the same size compact less than soil with a variety of particle sizes. Same size particles leads to high pore space. In opposite, a mixed distribution (collection of large and small particles) of particles can fill the pores with highly packed structure fulfilling in a more dense soil. A sandy loam soil (67 percent sand, 24 percent silt, and 9 percent clay) is the most susceptible to compaction (Kok, Taylor, Lamond. & Kessen, 1996). Soil with higher ratio of organic matter compacts less (Kumar, 2009).

Most of the organic matter found in soil profile is more elastic than soil. This helps in regaining of shape after load is removed. Moreover, organic material helps in creating larger and stronger soil aggregates. A high amount of organic matter is the best means to prevent surface crusting and soil sealing in all soils. Crop residue resist in making crust in top soil, which makes difficult for germinating seedlings to emerge out of soil. There is direct relation between soil compaction and number of microorganisms present in soil profile. Microorganisms balance the soil electrolytic environment and accumulate nutrient for plant growth. Low moisture and air in soil profile hinder microorganisms' development. This result in stunted vegetation growth.

This review concentrates mainly, though not exclusively, on soil compaction, its causes, concerns and alleviation methods for reducing soil compaction.

Soil Compaction Concerns

The tyres of heavy machinery compress the soil to a greater depth. Up to 70 cm depth of soil, higher bulk density results due to direct effect of soil compaction (Twum & Seth., 2015). This effect is pronounced in about 2-time increase in root biomass of Quercus petraea up to 70 cm depth of soil as compared to the uncompact soils. Beyond this depth, there was no significant difference in amount of root biomass with respect to increasing depth in both compacted and uncompact soils. Dest and Ebdon (2017) also reported similar results for Kentucky Bluegrass crop.

Compacted soil having bulk density greater than 1.7 g cm^{-3} reduced leaf area and shoot dry weight by 24-30% in barley (Mulholland, Black, Taylor, Roberts & Lenton, 1999). The same research also concludes that the root system of barley was heavily branched.

The effect of soil compaction on wheat crop is negative. The overall length of root and shoot of wheat are reduced due to high compaction (Latif, Khan & Ali 2008). As wheat is a shallow rooted plant, small root size results in low moisture pickup by the plant. Fresh and dry weights of the wheat plants also reduced due to delay in growth processes caused by compaction of soil. Lesser number of tillers were also observed. All these results ultimately leads to in poor yield of wheat.

Jordan Ponder & Hubbard (2003) found that severe soil compaction clearly reduced enzyme activity and nitrogen immobilization in oak seedlings in the soil. Tomasz (2011) studied change in root system morphology and productivity of alfalfa. In his first year experiment, he found that yield was significantly reduced but opposite effects were observed in second and third years. Large reservoir of water and plant nutrient in compacted soil contribute to the benefit of soil compaction. Alfalfa have root system characterized by ability to penetrate in severe soil compaction and changes its morphology to get sufficient supply of water and nutrients.

Grazing systems also have effects on soil compaction and pasture production. Soil depth up to 10 cm is reported to have increase in soil bulk density at field moist condition due to pasture grazing (Donkor *et al.*, 2011). This effect on soil properties was more pronounced in fall than in spring.

Compaction significantly affect root distribution in horizontal direction (Gilman, Ponder & Hubbard, 1987). Pancake root development is a classic example of root growth occurring under compacted conditions (Fig. 1). Root distribution is denser in upper soil layers then in un-compacted soil. In compacted soil treatments, 70% or more of the total root length was in the upper 12 cm of soil compared to 40% or less in un-compacted soil. No taproot development and increase in shallow adventitious roots were observed.

Fig. 1: Horizontal root distribution of corn in compacted soil (Image Source: Wolkowski & Lowery 2008)

Shallow root crops like soyabean is more sensitive to soil compaction than deep rooted crops. Beutler *et al.*, (2007) studied the effect of tractor traffic on soybean development. There was low development of deep roots and changed root distribution keeping the amount of root same as in un-compacted soil (Fig. 2). At penetration resistance of 2.33 MPa or higher and soil bulk density of 1.51 Mg m^{-3} or higher, significant decrease in soybean yield was observed.

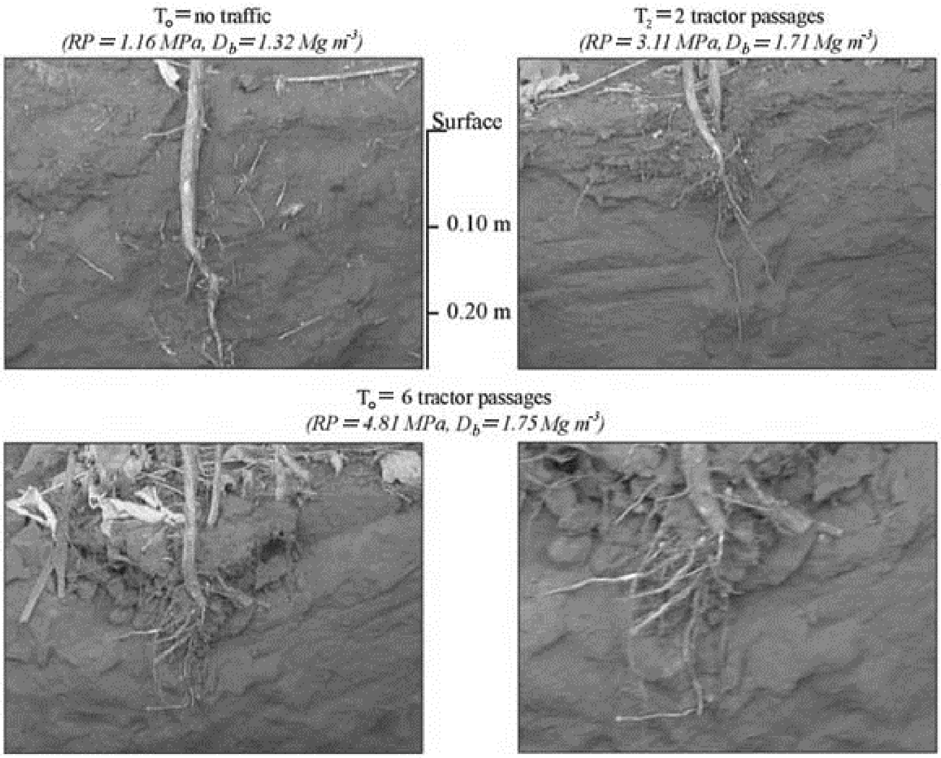

Fig. 2: Soybean tap root development profile under different number of passage of tractor- RP= Resistance to penetration, D_b= Soil bulk density (Image Source: Beutler, Centurion, Centurion, Freddi, Neto, Leone & Silva, 2007)

A relationship between nutrient assimilation and soil compaction was also observed (Kuht & Reintam, 2004). It was found that in heavy soil compaction, nitrogen uptake capability of spring wheat and barley is reduced by 30% and 40% respectively. Decrease in potassium and calcium by plants were also observed in the experiment results.

In hilly areas with sloping landscape, top soil compaction in sloping landscapes enhances runoff (Batey, 2009 and Alaoui, Rogger, Peth & Bloschl, 2018) and may induce erosion particularly along wheel tracks.

All the above studies conclude that compacted soil can reduce crop yield to significant amount due to decreased aeration, stunted plant growth, poor internal drainage, increased resistance to root penetration and limited availability of plant nutrients.

Soil Compaction Causes

Soil compaction is caused due to various agriculture practices. The main factors causing compaction of soil are:

1. Compaction from heavy machinery wheel traffic

Wheel traffic apply vertical downward force on surface of soil, which increase bulk density of soil (Hakansson & Reeder, 1994 and Gameda, Raghavan, Theriault, & McKyes, 1985). Shallow compaction caused due to heavy ground pressure (up to 5-10 inches) is usually eliminated with tillage practices. However, when axle load is high (>10 tons), deep compaction occurs. Amount of moisture also plays a greater role in amount of compaction (Soane and Van Ouwerkerk, 1994). In dry soil, bearing strength of soil is increased so there is no significant compaction. Soil below saturation level is mostly susceptible to compaction as depicted in Fig. 3. Saturated soils produce less compaction at shallow depth but there is more probability of formation of hard pan layer at some depth where soil remain undisturbed by tillage operations. Wet clay soil are most prone to compaction (Stoessel, Sonderegger, Bayer & Hellweg, 2018) as clay particle collect around water droplets acting as lubricants reducing soil-bearing strength.

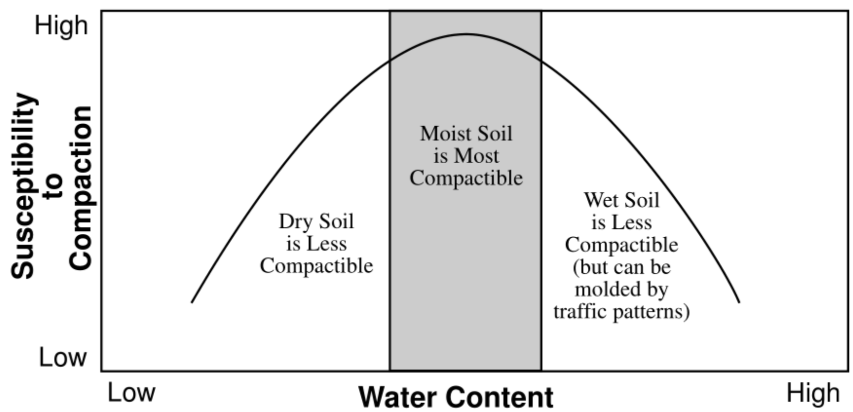

Fig. 3: Effect of soil moisture on its compaction (Image Source: Kok, Taylor, Lamond. & Kessen, 1996)

Experiment conducted by Beutler *et al.*, (2007) also confirms that after six passage of 11 ton tractor increases resistance to penetration to 6.75 MPa in 0.03 m to 0.06 m layer whereas soil bulk density to 1.81 Mg m^{-3}.

Heavy machines does not produce more compaction near the surface when compared to lighter machines but this is more prominent deeper within the soil profile (Schuler & Lowery, 1984).

Increase in width of tyres or use of dual tyres might reduce pressure on top soil but with same axle load, compaction at deeper soil is more pronounced.

2. Repeated Field Operations

Tillage process like repetitive moldboard plowing or use of sweep type tools at the same depth cause soil compaction at depth below the reach of normal tilling (Soehne, 1958). This is also known as tillage pans or plow pans (Fig. 4). Saturated or wet soil are most susceptible to this type of soil compaction as puddled soil squashes out of tyre path.

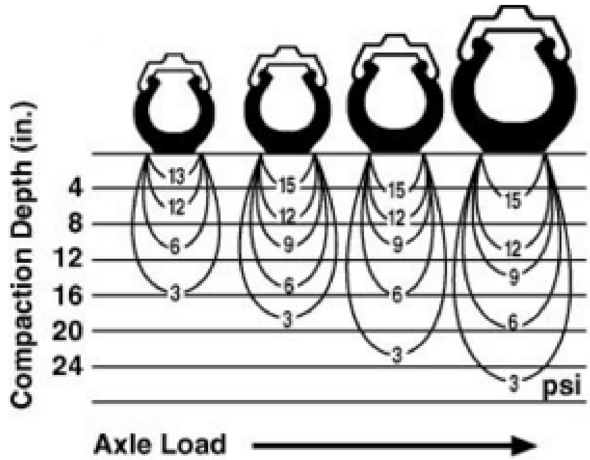

Fig. 4: Depth of compaction as axle load increases (Image Source: Voorhees, Nelson, & Randall, 1986)

Secondary tillage operations like disking increase soil susceptibility to compaction due to subsequent wheel traffic (Tullberg, 1990).

Mukesh, Rani & Kumar (2013) also concluded that there is no significant effect in bulk density of soil in tillage treatments like rotavator tilling except in zero tillage where an increase in bulk density is observed.

3. Lower diversification of crops

Crop rotation changes the amount of organic matter in soil (Campbell, Biederbeck, Zentner, & Lafond, 1991). Soil with low amount of organic matter causes it to compact more easily (Wortman & Jasa, 2003 and Nadian, Barzegar, Rouzitalab, Herbert & Hashemi, 2007). Sowing deep-rooted crops like carrot after shallow rooted crops like paddy in alternation maintain soil structure and helps in breaking hard soil pan formed due to puddling during paddy field preparation. Crop with high residue increase number of tillage operations to incorporate residue in soil increasing probability of soil compaction.

4. Time limitations

Time constraints in timely sowing of crops and availability of large machinery induce farmer to carry out tillage operation in too wet soil condition allowing no other choice. Considerable amount of soil compaction occurs when soil is in wet condition (Stoessel, Sonderegger, Bayer & Hellweg, 2018).

Soil Compaction Alleviation

Soil compaction alleviation practices are broadly grouped in two categories-

1. Avoid compaction

The best cure, economically and physically, for soil compaction is to avoid it. Reducing the axle weight (Gameda, Raghavan, Theriault, & McKyes, 1985) or use dual or track tyres reduce the vertical pressure on soil surface and hence soil compaction. Track tractors compact the soil considerably less for the same amount of tractor load due to greater contact surface (Taylor and Burt, 1987). Adjusting the tractor tyre inflation pressure reduces the soil compaction risk to some extent (Gotze *et al.*, 2016). Shallow soil compaction can be reduced by use of larger footprint tyres such as radial tyres. Tandem axles also reduces surface soil compaction largely. Tillage operation should be carried out at different depth every year. Farm operations should be formed at proper moisture content, as when soil water is high, there is increased soil compaction risk (Gotze *et al.*, 2016). Drainage problem should be resolved effectively. Various farm operations can be combined or integrated to minimize passes over field, such as use of drill cum rotavator machine. Integrated crop-livestock systems presence on cropland may have caused soil compaction (Bell, 2010), but it had no negative effect on soil properties or grain yield (Tracy & Zhang, 2008). Efficient and in peak working condition tillage equipment minimize the soil compaction.

2. Alleviate compaction problems

a. Optimized tillage operation

Surface compaction in top soil can be effectively reduced by moldboard tillage. Varying tillage depth while tilling reduces chances of hardpan formation. Field operations should preferably carried out when soil is in dry condition. Avoid use of unmatched equipment with tractor as under size equipment takes many passes and oversize equipment increase load on rear wheels. Fortune, Forristal & Kelly (1999) found that spiking treatments could be beneficial where specific shallow compaction problems occur but is unlikely to alleviate the effects of wheel traffic.

b. Subsoiling

Proper subsoiling alleviate the negative effects of soil compaction (Srinivas, Ramakkrushnan, & Vijayan, 2014). Subsoiling is beneficial when compaction layer is below 8-10 inches below soil surface. This is effective in breaking up compacted layers. It also assist in higher levels of water filtration thereby addressing drainage problems, higher aeration, and proper root development. Subsoiling may be ineffective in some cases due to reintroduction of compaction with subsequent wheel traffic. Subsoiling should be done at least 2-3 inches below hard layers to get maximum benefit. Moldboard tillage of the soil compaction pan is effective in removing surface compaction (Bauder, Randall & Swan, 1981). Annual subsoiling is more effective in reducing soil bulk density in comparison to biennial subsoiling, triennial subsoiling, or no subsoiling (Raper *et al.*, 2005)). Reductions in draft force were also found for annual subsoiling. Subsoiler with parabolic shanks disrupts higher volume of soil then subsoiler with straight shank.

c. Use primer crops

Primer crops which have taproots such as lucerne, lupins and chicory have ability to penetrate through compacted layers and hence crop rotation involving these crops considerably reduce the soil compaction (Unger & Kaspar, 1993). The research conducted by Materechera, Alston, Kirby & Dexter (1992) and Merrill, Tanaka & Hanson (2002) concluded that crops with tap-rooted roots could be used to create tillage like effects. This makes it possible to reduce the soil compaction by adopting a crop rotation with deep rooted crops. Elkins (1985) first proposed this method of using primer crops as tillage tools and later, Cresswell and Kirkegaard (1995) called this process as “biodrilling”. Soybean (Glycine Max L.) roots can be used to biodrills (Wang, Hesketh & Woolley, 1986) through a compacted soil pan to reduce compaction. These crops also add organic matter to the soil. Increased organic matter causes a smaller increase in the bulk density of the soil (Gemtos & Lellis, 1997) but the adverse effect of soil compaction on the crop yield are not significant. Nadian, Barzegar, Rouzitalab, Herbert & Hashemi (2005) and Ohu, Raghavan, McKyes, Stewart & Fanous (1985) concluded that organic matter decrease the soil compaction.

Cover crops like sun hemp, sorghum, millets can be introduced in crop production system. The cover crop can significantly reduce soil compaction in long term, instead of fallow land chiseling (Calonego., Raphael, Rigon, Neto & Rosolem, 2017).

d. Controlled traffic farming

Controlled traffic farming is the best practice to address soil compaction. In this system, a small portion of field is reserved every year minimizing traffic on remaining field (Fig. 5). However, this operation demands proper matching size of all equipment used in a crop field.

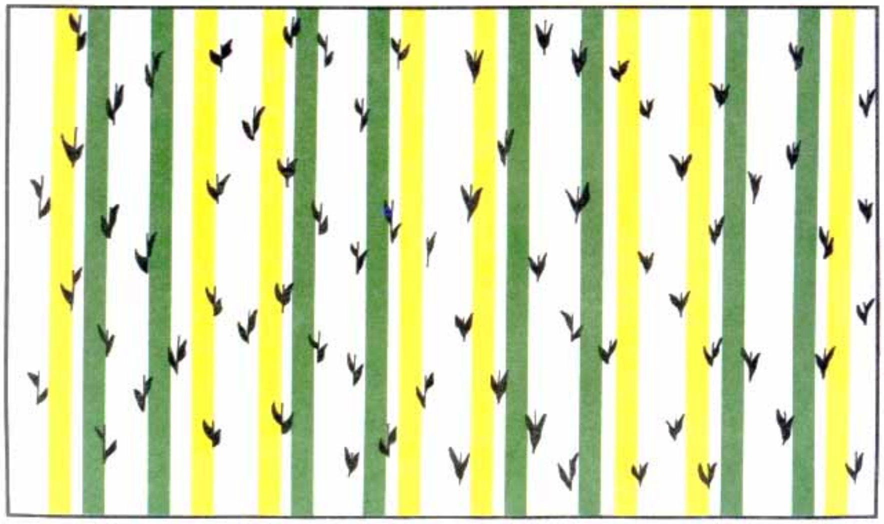

Fig. 5: Illustrative path of Planter and Sprayer (green), combine harvestor (yellow), for controlled traffic farming (Jones, Wiese & Dickey, 1999)

Restricting machine movement by laying permanent wheel tracks can be placed to confine compaction to specific zones (Froehlich & McNabb, 1983). Controlled traffic results into better root growth and lower resistance to penetration (Panayiotopoulos, Papadopoulou & Hatjiioannidou, 1994 and Wanink, Alblas, Werf & Akker, 1990). Reserved space also help in efficient traction. Raised bed farming can be very effective in application of controlled traffic farming. Raised bed significantly improve soil structure by lifting the soil above the saturated zone in high rainfall areas.

Conclusion

Heavier farm machinery and tractors have become common in agriculture to sustain demands of ever-increasing population all over the world. This process leads to problem like soil compaction and deterioration of soil health. Soil compaction negatively affects root growth of plants, storage and supply of water and nutrients. These adverse effects reduce crop production and increase waterlogging, runoff and soil erosion. The soil compaction results mainly due to repeated trafficking of heavy farm machinery in moist soil, malfunctioned farm practices with poorly maintained equiments and growing same crop year over year over a field. It is hard to suggest a single solution to alleviate soil compaction. Healthy farm practices like crop rotation with primer crops, tilling soil at different depths at proper moisture levels, employing euipments in peak working conditions and reducing vertical pressure of machines on land can avoid possible compaction. Compacted soil can be cured with subsoiling, spiking and bio-drilling. Laying down permanent tracks for tractors also minimize compacted area for crop cultivation. Further researches should be focused on to develop lightweight farm machinery.

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