SOIL COMPACTION AND DEEP TILLAGE – A REVIEW

M. Mohamed Amanullah, M. Srikanth* and P. Muthukrishnan

Department of Agronomy,
Tamil Nadu Agricultural University, Coimbatore- 641 003, India.

ABSTRACT

Soil compaction of agricultural land is an important form of physical land degradation. The continuous use of implements for years together develops a hard pan underneath which hinders the movement of water and inhibits growth and yield of crops. Hard pan prevent roots of many upland crops from penetrating into the deeper soil layer. Hence to break the soil compaction and hard pan deep tillage plays a vital role. To sustain the crop production soil compaction should be broken down. In deep tillage operation main factor is the soil type. Deep tillage will be beneficial if soil compaction is diagnosed. Deep tillage breaks the hard pan and helps in sinking down of the rainwater in the lower layer of soil from where it is not easily lost by evaporation and aids to deeper rooting, which helps in better exploitation of stored soil moisture and applied nutrients from the profile.

Key Words: Soil compaction, Deep tillage.

Soil compaction of agricultural land is a global problem and is an important form of physical land degradation (Van Ouwerkerk and Soane, 1994). The recent increase in the mechanization of agriculture and intensive agriculture are the main causes of soil compaction which leads to the formation of hard pan. In addition, reduced use of organic matter, frequent use of chemical fertilizers and plowing at the same depth for many years make the soil compact.

The tillage operations by farmers are generally performed with ordinary tractor mounted cultivators, usually tilling the soil to a depth of 15-20 cm. The continuous use of these implements for years together develops a hard pan underneath which hinders the movement of water and inhibits growth and yield of crops (Ishaq et al., 2000) Hard pan prevent roots of many upland crops from penetrating into the deeper soil layer. Hardpan soils have a dense layer which has few, if any, large pores which are important for good water infiltration and root growth. When there are no (or only a few) large soil pores the infiltration of rainfall is poor. This results in water ponding at the soil surface and/or more water runoff, and thus, poor moisture conservation. It is hard to suggest one single agronomic practice as solution to the soil compaction problem (Hamza and Anderson, 2005). The tillage which has been thought of merely disturbing the soil for some physical improvement, now has to be relooked into all possible ways in totality.

Deep tillage is one of the primary tillage operations which are done once in 2-3 years. But nowadays deep tillage is completely neglected. Deep tillage breaks the hard pan and helps in sinking down of the rainwater in the lower layer of soil from where it is not easily lost by evaporation and aids to deeper rooting, which helps in better exploitation of stored soil moisture and applied nutrients from the profile.

In soils that are prone to compaction and experience crusting and have low water infiltration capacity, deep tillage can increase root depth

* Corresponding author
improve infiltration and water storage (Sharma et al., 2004) and ultimately increase crop yield. Deep tillage has increased the yield of various crops viz; soybean (Wesley et al., 2001) and corn (Singh and Chaudhary, 1998 and Diaz-zortia, 2000). Hence, to reap higher benefits out of deep tillage, there is need to relook the same as a primary tillage operation.

Soil Compaction

Compacted soils occur when the stress on the soil from farm equipment exceeds the ability of the soil to support that stress. The soil is “squeezed” into a smaller volume (i.e. compacted) at the expense of the larger soil pores. Soil compaction is the greatest when the soil moisture content is high because water acts as a lubricant allowing soil particles to slide past each other as the soil is compressed.

Identifying a hardpan Soil: There are a number of symptoms that indicate hardpan soils viz., water ponding in the field following rainfall, uneven crop growth, poor penetration of tillage implements and/or high draft (horsepower) requirement and plant roots growing sideways after they reach a certain depth in the soil. In some cases, these symptoms may indicate other soil and/or plant problems and thus it must first be determined if the soil is actually a hardpan soil.

Effect of soil compaction: Compaction causes unfavourable changes in soil bulk density, porosity and penetration resistance (Soane et al., 1981). Adverse effects of compacted soil horizons on plant root growth and concomitant poor plant growth and yields have been recognized for many years (Jorajuria et al., 1997). Soil compaction effects extend beyond root morphology, affecting both shoot morphology and general plant physiology. A reduction in leaf area and shoot biomass was observed in maize plants grown on compacted soil (Ekwue and Stone, 1995).

Excessive soil compaction impedes root growth and plants, thus cannot explore the entire soil volume to meet their demand of soil moisture and plant nutrients because these become positionally unavailable. This, in turn, can decrease the plant’s ability to take up nutrients and water. Limited water and nutrient availability to plants due to compaction are major constraints to plant growth and yields in many soils. Lowery and Schuler (1991) studied effects of subsoil compaction on nutrient uptake by maize (Zea mays L.) and reported a severe deficiency of N and K in plants grown on compacted soil. Compaction can result in low water use efficiency (Ishaq et al., 2000), greater losses of plant-available water and less use of fertilizer (Stepniewski and Przywara, 1992).

Deep Tillage

Deep tillage is a practice that breaks up soil, usually 12-18 inches deep, to allow increased water movement, better aeration of the roots and access to additional minerals and nutrients for plant growth. By comparison, conventional tillage breaks up the soil 6-8 inches below the surface, and in areas of heavy compaction, such a practice is not adequate. Deep tillage is normally a very aggressive tillage operation, designed to break up the soil and mix the residue in with the soil. Main concern for deep tillage is to reduce the soil compaction caused by vehicular traffic, to break the hard pan, to decrease the soil bulk density and soil strength for deeper rooting of crops, to explore the entire soil volume for water and nutrients, to increase the infiltration rate and to decrease the soil temperature.

Agronomic considerations: The effects of this practice can be enhanced where restrictive layers are a concern by including deep rooted crops in the rotation that are able to extend to and penetrate the restrictive layer. This practice should not be applied...
where unfavourable soil materials such as high sodium, calcium, gypsum or other undesirable materials, are within anticipated deep tillage depth and would be brought to the surface by deep tillage operations. To help reduce compaction, it is desirable to conduct normal tillage operations when soil moisture is less than 50 per cent of field capacity.

**Effect of deep tillage**

**Deep tillage on soil “C” stocks:** Immediately following a tillage event, large amounts of CO$_2$ are lost from the soil (Reicosky et al., 1997, 2005). Soil organic matter is physically protected from decomposition when it is located within aggregates or in pores small enough to limit microbial accessibility and preclude microbial attack (Sollins et al., 1996).

Tillage frequency, depth and intensity all act to influence how much tillage disturbs soil structure and physical protection of soil C from decomposition. Textural soil pores inter-spaces between primary particles are a function of soil particle size distribution and tend to be relatively stable (Leij et al., 2002). In contrast, structural soil pores inter-spaces between soil aggregates are very susceptible to disturbance due to deep tillage. Structural soil pores tend to be longer and thinner than textural soil pores. Soil C located with structural pores is thus well-protected from decomposition, but that soil C is vulnerable to loss following tillage (Reicosky et al., 2005). Macroaggregates can be broken up by shearing forces during deep tillage. A large portion of physically protected soil C resides in microaggregates located within macroaggregates (aggregates larger than 250 mm) (Blanco-Canqui and Lal, 2004; Denef et al., 2002).

**Deep tillage on soil physical properties:** Deep tillage improves the physical conditions of the soil there by ultimately increases the yield (Mohanty et al.2000).

**Water infiltration characteristics:** Subsoiling has a striking effect on the soil physical properties within the subsoiling zone. The final infiltration rate, soil water transmissivity and sorptivity of the transmission zone increases with increase in intensity of subsoiling due to the opening of the channel by the subsoiler (chisel plough).

**Soil penetration resistance and bulk density:** In general, soil penetration resistance (SPR, MPa) decreases significantly under subsoiling compared to conventional tillage due to the effect of subsoiler (chisel plough). It is also attributed to the shattering effect on soil by subsoiler and introduction of fracture or disruption on planes throughout the soil, which facilitate greater recharge of the soil profile.

**Bulk density and porosity:** Decrease in bulk density and increase in soil porosity to a greater degree, as a consequence of deep tillage, is attributed to the change brought in pore geometry. Bhusan et al. (1973) have also reported that deep tillage results into more stirring (loosening and mixing) of soil decreasing the large size aggregates (2 to 5 mm), but improved the granulation of smaller aggregates (1 to 0.1 mm) and thereby increased the total pore spacing of the soil, and consequently decreased the bulk density in both surface and sub soil layers, as a consequence of enhanced and proliferated root growth.

**Basic infiltration rate and hydraulic conductivity:** Deep tillage increases the basic infiltration rate of soil. Pelegrin et al. (1990) have reported that the difference in infiltration rate could be caused by a different structure pattern with a different pore system being created by them due to the influence of plough pan. An improvement in basic infiltration rate and hydraulic conductivity of the soil due to chisel tillage is attributed to a significant change in the soil pore geometry and enhanced root growth in the surface soil layer.

**Soil chemical properties:** Soil organic matter strongly affects soil properties such as water infiltration rate, erodibility, water holding capacity and nutrient cycling (Wander and Yang, 2000). It is suggested that proper management of SOM is the heart of sustainable agriculture (Weil, 1992). Recent
research has also recognized SOM as a central indicator of soil health. Therefore, it is important to maintain proper levels of SOM to sustain soil productivity.

Intensive agricultural practices change SOM characteristics greatly, generally a substantial loss of soil organic C (SOC). Change in frequency and intensity of deep tillage practices alters soil properties, distribution of nutrients, and soil organic matter in the soil profile. These changes become stable with time and could affect availability of nutrients for plant growth, crop production and soil productivity.

Deep tillage is the principal agent producing soil disturbance and subsequent soil structure modification, increasing potential soil organic matter loss by erosion and biological decomposition (Hussain, 1997). Deep tillage does not affect the pH, electrical conductivity and Cation exchange capacity CEC as the depth of ploughing increases. An improvement in the level of available P in the soil under deep tillage has also been reported by Gaikwad and Khuspe (1976). The favorable effect of deep tillage, in improving the soil parameters, is an outcome of increased proliferation of roots and microbial activity, which in turn have released the organic acids and releasing the native phosphorus and potassium from the soil, apart from reduction in fixation of applied phosphorus.

Soil biological properties

Earthworm: Tillage can affect earthworms directly by the mechanical actions of the tillage operations as well as indirectly as a result of the consequent changes in soil environment. The latter include destruction of burrows, redistribution of litter and changes in soil physical conditions such as water content and temperature.

Gerard and Hay (1979) compared deep ploughing, normal ploughing, tined cultivation and no-tillage in a long-term tillage experiment on two soils in England. Earthworm number was the lowest with deep ploughing rising progressively through tined and normal cultivation to the highest numbers with no-tillage. These authors attributed the highest population found under no-tillage to reduced mechanical damage during ploughing and harrowing as well as higher soil water content and litter layer in the spring due to the lack of soil disturbance. These factors tended to encourage longer periods of feeding and cocoon production.

The plough cuts a slice of soil which is then partially inverted, burying earthworms and cocoons from the surface layers. In contrast, the tines tend to shatter the soil, possibly damaging many earthworms in deeper layers and this is repeated up to three times in the autumn and early winter. With deep ploughing, soil inversion is more complete causing a further reduction in the number of A. chlorotica and also A. longa (Gerard and Hay, 1979).

Effect of deep tillage on crop production:

Deep tillage can increase root depth (Lampurlanes et al., 2001 and Rajkannan and Selvi, 2002), improve infiltration and water storage (Sharma et al., 2004), and ultimately increase crop yield. Deep tillage has increased the yield of various crops viz; soybean (Wesley et al., 2001), corn (Singh and Chaudhary, 1998 and Diaz-zortia, 2000) and sorghum (Rajkannan and Selvi, 2002).

Deep-tillage break up high density soil layers, improves water infiltration and movement in the soil, enhances root growth and development, and increases crop production (Bennie and Botha, 1986). Sene et al. (1985) concluded that increments in corn yield due to subsoiling are highly related to the soil texture and the soil structure.

Yield and water use efficiency: The results of an experiment conducted to find out the effect of tillage practices on seed yield of soybean indicated that subsoiling is advantageous in vertisols of central India during drought situation as on an average subsoiling recorded 20% higher yield over conventional tillage (Gosh et al., 2006). Wesley et al. (2001) also emphasized that subsoiling in the non-irrigated environment recorded 46% greater soybean
yield and net return than conventional tillage, whereas in the irrigated environment there was no significant difference between these two tillage systems.

Heatherly and Spurlock (2001) reported that yield and net returns from deep tillage in soybean was greater than the shallow tillage system in a clay soil but the increased profits from deep tillage were infrequent in a three years study. In fact, the increased crop yield of soybean under subsoiling is associated with increased water storage in the soil profile because of greater infiltration resulting from improvement in water transmission properties and macro porosity due to subsoiling and thereby increasing the availability of nutrients. Wesley et al. (2001) also reported an improved water status resulting from subsoiling in soybean on clay soil. Their results indicated that subsoiling is advantageous in vertisols of central India during drought situations. Under uneven and deficit rainfall situation, subsoiling is superior to conventional tillage system and thus, minimizes the risk of failure of soybean due to water deficit.

**Grain and straw yield:** In an experiment conducted by Patil (2001) to study the effect of different tillage practices on growth and yield of sorghum, tillage depth considerably influenced the growth, yield attributes and yields of winter sorghum. The trend in straw yield was also similar to that of grain yield in shallow, medium and deep tillage practices during both the years of study.

Higher grain and straw yields obtained in deep tillage as compared to medium and shallow tillage was attributable to higher water content in the top 0.60 m soil profile after deep tillage compared to medium and shallow tillage at sowing, at different stages of crop growth and at harvest during both the years of study.

**Deep tillage on weed management:** Deep tillage is an important cultural practice that affects weed management. Vertical distribution of seed in the soil profile can affect the level of seed dormancy, seed longevity, emergence depth and seedbank depletion by emergence (Yenish, 1992). Density and composition of seedbanks varies according to tillage system and depth.

Generally, mouldboard ploughing increased weed seed banks when combined with frequent fallowing. Conversely, chisel plowing combined with barley cropping generally reduced weed seed bank sizes. A soil seed bank consists of all viable seeds and vegetative propagules present on and in the soil. These soil banks range from near 0 to as much as 1 million seed per m². Seed banks of weed species vary greatly in composition and density in the soil in association with cropping history (Buhler, 1997), tillage or crop rotation. The annual variation in seed bank composition may be caused by variations in crop type, time of seedbed tillage, previous year’s seed production, herbicide efficacy, pathogen attacks, and insect consumption. (Ghosheh and Al-Hajaj, 2005)

Altering tillage practices changes the composition, vertical distribution and density of weed seed banks in agricultural soils. Tillage systems provide weed seeds with different soil micro environments due to differences in soil porosity, bulk density and soil surface conditions.

**Deep tillage on disease and insect management**

Deep tillage practices are valuable methods of controlling disease and are an integral part of sustainable agriculture (Steinkellner and Langer, 2004). The distribution of S. minor sclerotia is greatly influenced by agricultural practices, such as irrigation and tillage (Wu and Subbarao, 2003). Deep ploughing can reduce the incidence of lettuce drop by removing sclerotia from top layers of the soil, Deep tillage has been found to change the soil environment reducing the incidence of Fusarium root rot (Harveson et al., 2005).
The causal organism for rice sheath blight is *Rhizoctonia solani*. The pathogen survives in soil as sclerotia. These sclerotia will spread and cause disease. By the action of deep tillage the sclerotia gets deeply buried into the soil. Downy mildew of pearl millet is caused by *Sclerospora graminicola*. The oospore remains viable in soil for 5 years or longer giving rise to the primary infection on the host seedling. Deep tillage tends to suppress the oospore by deeply burying it. Deep tillage is generally recommended as a cultural practice to reduce the incidence of maize downy mildew and cotton verticilium wilt.

The type and timing of tillage can markedly influence the soil environment and affect the survival of insect pests. Deep ploughing is often helpful in reducing the overwintering population of *Helicoverpa armigera* and several species of cutworms that undergo diapause in the soil during winter. Deep tillage immediately after harvest of wheat crop in April-May is helpful in exposing the resting grubs of rice root weevil to their natural enemies like birds and to the action of wind. Deep tillage is also helpful in minimizing the infestation of armyworm in cereal crops, white grubs attacking groundnut and chillies, pupae of hairy caterpillars attacking groundnut, greengram, etc.

Deep summer ploughing also influences population of plant parasitic nematodes. Deep tillage in banana field significantly reduced the incidence of burrowing nematode *Radopholus similis*. Deep tillage is recommended as a cultural practice in tomato growing regions to reduce the incidence of root knot nematode *Meloidogyne incognita*. In citrus growing regions where the incidence of citrus nematode *Tylenchulus semipenetrans* is severe deep ploughing is recommended. By deep tillage the soil temperature gets increased and also the nematodes are exposed to hot sun where they cannot survive.

**Ways to reduce soil compaction**

**Optimum soil moisture:** Field operations should be performed at optimum moisture conditions, allowing more drying time for fields that tend to remain wet.

**Addition of organic matter to the soil:** Crop residue, animal manure, sludge, and green-manure crops all provide organic matter that can promote good soil structure and decrease bulk density. The soil resulting from these additions will be more resistant to compaction by tillage or wheel traffic.

**Crop rotation:** Crop rotations including perennials such as alfalfa, clover, and grass result in less compact soils. This effect stems from (1) absence of tillage operations after seeding, (2) field operations that are typically limited to hay harvesting when the soil is dry, and (3) deeper rooting that keeps the soil more porous and removes large amounts of water, thus promoting soil drying and cracking.

**Altering the depth of tillage:** It is important to till deeper in a dry year to break up the “tillage pan.” In subsequent years, the tillage depth should be varied to minimize development of a compacted zone.

**Controlling wheel traffic:** Compaction can be localized if all tires are restricted to the same tracks or row middles. Using tilling, planting, spraying, and harvesting equipment that has the same wheel spacing makes it easier to control traffic that causes compaction. Wheel traffic is easiest to control in conservation-tillage and no-tillage systems.

**Use deep tillage when compaction limits crop yields:** Visually inspect crop roots to help you determine the depth and extent of compaction. The subsoiler or chisel plow are the most common tools used to break compaction.

**Manage livestock grazing:** Livestock should be allowed to graze on cropland only when the soil is dry or frozen. Use rotational grazing and adjust stocking rates to match soil and forage conditions.

**Merits of deep tillage:** Deep tillage posses many advantages for farmers. It breaks up high density soil layers, It improves the physical condition of the soil, deep tillage in clay soils often benefits both the crop roots and drainage of the soil and thus may
overcome both moisture deficit problems during the dry season and problems of excessive moisture during the rainy season. It enhances the nutrient availability, decreases soil bulk density. It make the plants to explore the entire soil volume for water and nutrients, it improves water infiltration and movement in the soil. Increases the water use efficiency, it enhances the root growth and development, it alters the population of weed seed bank, it brings down the pest and pathogen incidence and it increases crop yields.

**Demerits of deep tillage:** As deep tillage offers many advantages it has its own disadvantages being high energy requirement, deep tillage should only be carried out when the soil is dry or slightly moist, which is more difficult in clay soils, deep tillage in when the soil is dry requires a lot of power and often it leaves large aggregates with big spaces between them, providing unfavourable conditions for germination and initial plant growth, deep tillage clay soils in moist conditions creates a channel where the point of the subsoiler has passed, without loosening the profile and breaking up the compacted layer, the beneficial effect of deep tillage lasts only for a very short time in some soil types, particularly in hardsetting soils, raises production cost and rapid decomposition of organic matter.

**CONCLUSION**

To break the soil compaction and hard pan deep tillage plays a vital role. To sustain the crop production, soil compaction should be broken down. In deep tillage operation main factor is the soil type. “Not all soils are generally susceptible to soil compaction, and hence, not all soils will benefit from deep tillage.” Deep tillage will be beneficial if soil compaction is diagnosed. Deep tillage breaks the hard pan and helps in sinking down of the rainwater in the lower layer of soil from where it is not easily lost by evaporation and aids to deeper rooting, which helps in better exploitation of stored soil moisture and applied nutrients from the profile.

**REFERENCES**