REVIEW ARTICLE

SOIL COMPACTION: ITS CAUSES, EFFECT AND SOLUTION IN AGRICULTURE

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Received-05.04.2022, Revised-18.04.2022, Accepted-28.04.2022

Abstract: In modern agriculture, most of the field operations from sowing to harvesting are done mechanically by using heavy agricultural machinery and equipments/implements. However, the loads from these heavy machineries may induce stresses exceeding soil strength causing soil compaction. Field preparation with large and heavier agricultural machinery induced hard pan/plough sole at the depth below the tilled zone of approximately 20 cm (sub-soil compaction). This is more serious problem because alleviating procedures such as sub-soiling or deep tillage is difficult and costly, over and above normal tillage. The magnitude of top as well as sub-soil compaction, however, depends on the type of tillage equipment, intensity of tillage, soil properties (texture, organic matter contents etc.) and the soil moisture content at the time of tillage.

Keywords: Soil compaction, Soil properties, Plant growth, Crop yields

INTRODUCTION

The diminishing agricultural land due to urban and industrial expansion and utilization of land for disposal of hazardous by-products of the industries, coupled with the increasing demand for food and higher input cost have put pressure on the agricultural scientists to increase the productivity of existing agricultural soil and the efficiency of agricultural production. Till now, the need of higher production has been met by the batter irrigation facilities, improved weed and pest control, breeding of high yielding and disease resistant crop cultivars, use of batter farm machineries and implements, increase in intensive cropping practices etc. But increasing mechanization and trend towards the use of large and more efficient farm machinery (tractors and other tillage and harvesting equipments/ implements) and intensive cropping practices have led a gradual densification of soil and a corresponding reduction of soil productivity (Gameda *et. al*., 1987). The susceptibility of soil to compaction has also risen due to excessive use of inorganic fertilizers and over tillage practices that have led to a gradual reduction in organic matter in soil.

Compaction of soil has, thus, become a problem of worldwide concern. Apart from reduction in yield of various crops, soil compaction results in higher fuel requirement for tillage operations. Slower internal drainage of compacted soil impedes water redistribution and drainage performance, prolongs the time when the soil is too wet for tillage, higher runoff and soil erosion, higher operational costs of irrigation due to poor infiltration and presumably higher evaporative losses. Low efficiency of fertilizer, future costs of restoring soil structure and a number of other factors have also been mentioned in the literature.

Ploughing of field with large and heavier field equipments/implements, compaction of soil has increased at the depth below the tilled zone of approximately 20 cm (sub-soil compaction). This is more serious problem because alleviating procedures such as sub-soiling or deep tillage is difficult and costly, over and above normal tillage. The magnitude of top as well as sub-soil compaction, however, depends on the type of tillage equipments, intensity of tillage, soil properties (texture, organic matter contents etc.) and the soil moisture content at the time of tillage. Raghavan, (1990) reported in their review article on soil compaction in agriculture that coarser textured soils tend to compact maximum at lower moisture content than finer textured soils and also tend to have lower soil moisture retention capacities. The soils, however, require higher moisture content to achieve the equal compaction levels if organic matter content is higher. Low water retention, inherent poor fertility and rapid development of mechanical resistance (compaction) to growing roots in coarse textured soils often lead to reduced plant growth and development because of reduced proliferation of roots, reduced water and nutrient availability, and limited aeration and hence low crop yield. Management practices that encourage deeper and denser rooting to capture downward moving water and nutrients and to extract from greater depths are likely to enhance crop yield.

Many scientists have reported that deep tillage enhanced crop yields by encouraging vertical and horizontal proliferation of roots through reduction in soil strength in the sub-soil. Majority of the information is on tillage benefits in crop with fibrous root system e.g. millet, corn and sorghum, but there are very few reports on deep tillage effect on crops with tap root systems such as, mustard. Owing to the thick and less branched roots in tap rooting crops, tillage induced reduction in soil strength of sub-soil is likely to have greater influence on root growth and crop yield.

Among tap root crops, mustard is a major oil seed crop grown under wide range of soils varying from

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sandy to clay loam in texture, but thrives best on the light loam soils that are more sensitive to compaction. Being a tap rooted crop, its production is severely affected if the sub-soil is compacted or has developed a plough sole (hard pan) and is further reduced when soil moisture is limited.

Soil Compaction:

There are several terms often used in literature to define soil compaction. It is, therefore, necessary to differentiate these terms before continuing further. Bradford and Gupta (1986) described these terms as follow:

Compression:

It refers to a process that describes the decrease in soil volume (soil densification) under an extremely applied load. Applied load can be in the form of vibration, rolling, tamping etc.

Consolidation:

Compression of saturated soils is called consolidation.

Compaction:

Compression of unsaturated soils is called compaction i.e. compression of a mass of unsaturated soil into a smaller volume. So, during consolidation, water is excluded from voids of the soil matrix, whereas during compaction soil air is excluded from the voids of the soil matrix. Consolidation tests which are in use represent extreme conditions during which maximum densification of soil is possible. The results of these tests are mainly used in the design of building foundation, but have very limited application to agriculture, as the soil in the farm/agricultural fields are often unsaturated.

Compressibility:

Soil compressibility refers to the ease with which soil decrease in volume when subjected to mechanical load.

Compactibility:

It is the maximum density to which a soil can be packed by a given amount of energy. There is a saturated method called “Proctor Test” for determining soil compactibility. In this procedure, the soil is compacted in a metal mold by a set number of impacts from a free-falling hammer and the soil density obtained at a series of soil water contents is used to define compactibility (maximum density) for a given energy level.

Compaction has been used for characterization of soils, both in laboratory as well as in field. In laboratory, soil compaction refers to the compression of small homogeneous soil samples, whereas in field it is refers to the simultaneous densification of several soil horizons in the profile. In general, compressibility describes soil compaction in the laboratory. However, no single property is available to describe soil compaction in field. It is important to mention here that soil compaction has often been used or understood to have bad connotations, however, not all soil compaction is bad. There is time, when seedbed compaction is needed to improve seed soil contact. Therefore, it is necessary to differentiate good or acceptable compaction from harmful or excessive compaction.

Process of soil compaction:

The compression of a mass of soil in to smaller volume is accompanied by change in soil's structural properties, thermal and hydraulic conductivity and gaseous transfer characteristics. These in turn affect chemical and biological balance. In other words, the soil environment is changed in such a way as to affect all soil process to a greater or lesser extent, depending on the degree of compaction. The degree of compaction is usually expressed in terms of change in the dry bulk density, porosity and/or penetration resistance as function of applied pressure and soil moisture content. The change in the dry bulk density is the most frequently used parameter in compaction research and can be measured by core sampling etc. Porosity is easily derived from dry bulk density by knowing the specific gravity of soil solids. Both, porosity and dry bulk density are indirect measures of water movement aeration characteristics. Whereas, penetration resistance is used as a measure of soil strength and mechanical impedance to root penetration, but problem of interpretation of data to concomitant variables such as moisture content just prior to and after compaction must be known of interpretation of penetrometer data and of the changes in bulk density.

Characterization of soil compaction:

The characterization of soil compaction is a subject of controversy because the parameters that best describe compaction (bulk density, porosity or penetration resistance etc.) by the wheels of tillage machinery (tractors) are not directly coupled to crop response. Neither the change in compaction related parameters due to decompactive processes (tillage and natural alleviation) are well described. Realizing this problem, Soane and Boone (1986) suggested that new structural indices be developed to provide stronger links between traffic-soil and soil-plant interactions. Consequently, Boone (1986) made some efforts in this direction and described the concept of critical soil density in relation to optimality of various plant related processes. The key is to identify limiting factors for the given crops, soils and climatic condition and to establish relationship between soil compactness and the major soil related limiting factors. In some situations, the limiting factor may be moisture, in others it may be aeration or nutrient status. Raghavan and Ohu, (1985) reported that, regardless of quantitative definition, loss of structure might be discerned visibly in case of excessive compaction. Excessively compacted soils suffer from poor aeration and low hydraulic conductivity and hence produce poor crop yields. Less than excessive compaction is not necessarily detrimental to crop growth (Raghavan and McKyes, 1983).

Excessive compaction:
There are three variables, which define soil and plant limiting conditions (Gupta and Larson, 1982) arising from soil compaction.

1. Air-filled porosity critical for gaseous diffusion
2. Critical stresses for shearing soil aggregates
3. Soil resistance critical for root growth
4. Hydraulic properties of soils

The literature about the limits of these variables in defining excessive compaction is not only limited but also confusing.

Air-filled porosity:
Gupta and Larson (1982) assumed 10% air filled porosity as a critical value below which gaseous exchange with the atmosphere may restrict biological activities. The limiting air-filled porosity, however, depends upon the types of plant.

Critical Stresses:
Critical stresses for shearing soil aggregates are based on the hypothesis that pore water pressure changes when the majority of soil aggregates shear during compaction (Gupta and Larson, 1982). The stress value corresponding to the peak pore pressure is defined as the stress at which the soil aggregates shear. During the initial application of an applied load, the number of contacts of each aggregate increases i.e., each aggregate comes in contact with the surrounding aggregates. Each new contact produces a new meniscus, which acts to pull water from within the aggregates and hereby reduces the pore-water pressure. As additional mechanical stress is added, the new contact area increases more slowly i.e., little changes in pore-water pressure occurs until pores between the aggregates become small enough for the menisci to coalesce i.e., the pores fill with water, and then the pore-water pressure increase. As the pore–water pressure approaches zero from the negative, aggregates strength decreases rapidly, where upon further application of applied load shears the aggregates and destroy the identity.

Soil resistance critical for root growth:
A penetrometer resistance of 2.0 MPa assumed critical for root penetration based on relationship of cotton root penetration to penetrometer resistance (Taylor and Gill, 1986) obtained a similar value for pea seedling in a fine textured soil. Gerard *et al.*, (1982) however showed that penetrometer resistance above which root growth is negligible varies with the clay content i.e. decrease with increase in clay content. In addition, critical penetrometer resistance depends upon the type of root system and the type of penetrometer. The other disadvantage of using penetrometer resistance, as an index of excessive soil compaction is an insufficient data base for penetrometer resistance as a function of soil water content and bulk density. Russel and Goss (1974) presented a relationship of root elongation to applied pressure on the roots of barley plants. The root elongation rate was reduced by 50 to 80 % at applied stress of 20 and 50 KPA, respectively. They suggested that such relationship could be used directly to compute applied loads large enough to limit root growth for maximum yields. These relationships also eliminate the need for instrument-dependent measurements, such as penetrometer resistance.

Hydraulic properties of soil:
Excessive compaction impedes the flow of water and thus reduces the effectiveness of drains, particularly in fine textured soils, where drains are installed to improve the inherent poor drainage characteristics. At present there is a limited data based on the changes in soil hydraulic characteristics as influenced by applied load. Akram and Kemper (1979) showed the effect of compacting load and water content at the time of compaction on infiltration rate, compaction and bulk density of soil in a laboratory study. Compaction load of 0.346 MPa at field capacity on sandy loams and finer textured soils reduced infiltration rate to < 0.1 % of value obtained after these soils had been compacted when they were air dry. In a loamy soil, this reduction was about 1.0 %.

Critical infiltration that may define excessive compaction depends upon the rainfall intensity of the area. At a minimum, the critical infiltration rate for a given load and the soil water content should be equal to the rainfall intensity. This, however, complicated when the variation in the rainfall intensity from year to year and changes in hydraulic properties with soil depth are considered.

Susceptibility of soil to compaction:
It implies the rate at which soil compresses with applied load at a given degree of saturation. In other words, ease of soil to compaction is a property of soil and is analogous to the compression index. The compression index increases with increasing clay content up to 33 % and then levels off (Gupta *et al.*, 1985). Higher values of compression index signify higher compressibility or greater compaction of a soil. It means clay soils are more while sandy soils are least susceptible to soil compaction. However, soils with higher compression index are not necessarily satisfactory for root and plant growth. Soils with higher compression index simply exhibit large changes in the air-water-soil matrix relationship for an increment of applied load. It is possible that these soils have a less than limiting air-water-soil matrix relationship (lower bulk density), even after a load has been applied. Hence, the ease/susceptibility of soils to compaction does not give enough information to describe degradation of soils as a medium for plant growth. What we need is a comparison of air-water-soil matrix relationship at various applied load to the limiting values for root and shoot growth which will not only define the relative ease of soils to excessive compaction but also delineate the range of stresses and the soil water

contents that will not be conductive to excessive compaction.

Soil response to compaction:

In general, agricultural soils are subjected to two types of machinery traffic in various sequences, that which compacts (wheel traffic) and that which loosens and redistributes through part of the depth profile i.e., tillage traffic. The effect of both the wheel traffic and the tillage traffic is not entirely independent in practices as soil response to each is a function of conditions established by the previous operation and the summation of natural forces acting in the interval.

Soil response to compaction is known to be function of traffic parameters, soil properties and soil moisture content at the time of traffic. Raghavan *et al.*, (1976) observed a change in bulk density of sandy loam soil from 0.1 to 0.5 Mg m^{-3} at the depth of 15-20 cm by wheel traffic. The magnitude of density changes was found to depend on the soil texture, soil moisture content, contact pressure or axle load and number of passes. The region of maximum compaction for lighter vehicles was in top soil (0-30 cm), whereas, heavy vehicles compacted the sub-soil (30-60 cm). The increasing weight of agricultural vehicles and adoption of minimum cultivation have increased the importance of compaction by wheels in changing the structure of agricultural soil. The change of soil packing state following wheel passage have already been emphasized i.e. bulk density and soil strength may be increased, while soil porosity and permeability may be reduced. Increases of bulk density below 10 cm are considerably influenced by wheel load (Blackwell and Soane, 1981). Ohu *et al.*, (1986) showed a shift of optimum to higher moisture contents with increasing organic matter content as well as lower shear strength for equal compaction levels.

Crop response to compaction:

Plant growth involves physical, chemical and biological processes. In crop production, there are two areas of activities – the soil and the atmosphere. The demand on the root system at any given time are governed by photosynthetic potential which is considered as some combination of available light, CO_2 and plant ability to absorb these by the above ground portion of the plant. The degree to which photosynthetic potential is achieved at any time depends on the ability of plant root system to supply water, nutrients and oxygen from the soil and to exhaust respiratory CO_2. Maximum growth is obtained when the root system can meet the demand of photosynthetic potential given that the soil contains at least an adequate nutrient and water supply as well as efficient mechanism for gaseous exchange. Maximum yields are obtained when conditions are optimal throughout the growing period i.e., when a temporal coherence between plant development, weather, and soil conditions through the profile is maintained.

In compacted soils, this balance can be upset. The higher mechanical impedance of compacted soils, or compacted layers, restricts the depth of root penetration as well as overall root density (Raghavan *et al.*, 1979). The most obvious effect of restricted root penetration on the plant is reduced access of water and nutrients. Limited penetration to the sub-soil can be critical during dry season. Lowery and Schuler, (1994) studied the effect of compaction on soil and plant growth and reported that mechanical impedance to root growth has been shown to limit root elongation is related with the reduction of plant shoot and grain yield. They observed reduction in leaf nutrient concentrations that apparently affected crop yield in compacted soils. Unger and Kaspar, (1994) observed that the compaction also reduces plant growth and yields by affecting water infiltration, aeration and disease pressure.

Kumar *et al.*, (1994) studied the effect of soil compaction on root growth and yield of peas growing in silt loam soil and reported that the dry matter content was more in soil of lower bulk density and decreased with the increase in bulk density. Better root penetration in soil having low bulk density was due to better crop growth and pointed out that cotton roots did not penetrate a soil with bulk density more than 1.8 Mg m^{-3} and decrease in porosity viz. number and size of pores may lead to impedance to root growth. But contrary to this was observed in sandy soils. Mathan and Natesan, (1993) observed that the compaction in sandy soil increase the yield of maize and also nutrient uptake by the crop was increased.

Soil compaction has been reported to reduce the yield of grassland by 7-26 % (Moreno *et al.*, 1997). Compaction studies have resulted in the recognition of important general relationship between soil compactness and yield (Raghavan *et al.*, 1979). The essential features of these studies are that the compactness degree at which maximum yield is obtainable depends upon the weather regimes. In dry years, better yields were obtained on a slightly compacted soil than a loose soil. Raghavan and McKyes, (1983) attributed this to differences in available moisture because uncompacted plots had very low moisture due to high evaporative losses where highly compacted plots held the water tightly in small pores. The water balance was more favourable at intermediate levels of compaction.

The definition of soil compaction is not fully describing the resulting effect without other factors being accounted for. e.g., root water extraction is more directly affected by pore size distribution and continuity of pores rather than by total porosity. The change in pore size distribution due to compaction is mainly at the expanse of large pores associated with aeration and available water and degree of compaction is a function of infiltration rainfall. The sensitivity of crops to compaction depends upon species. We may expect deep-rooted species to be less sensitive to compaction, since they are adapted to penetrating typically too dense sub-soil layers. Other characteristics such as drought resistance or resistance to excessive moisture may be indicative of lower sensitivity to compaction. Vigier and Raghavan, (1980) suggested that the restricted root proliferation could even reduce the ability of root systems to overcome harmful effects of topsoil resident pathogens. Compaction induced changes in the air-water regime affect microbial activity such that the nitrogen balance favours ammonium over nitrate nitrogen as compaction levels increase with unfavourable effects on yield (Sheptukhov *et al*., 1982).

Soil and crop response to tillage:

Tillage refers to the different mechanical manipulations of the soil to provide favouable soil environment to crop growth. Although there has been very good progress in the development of suitable tillage implements, but tilling of soil is still the most difficult and time-consuming task in the crop production. The need of tillage warrants careful consideration in the view of increasing energy crisis. There is a plenty of scope in reducing the expenditure of tillage operations and batter results are possible if the objective of tillage is carried out at the proper time. Larson and Osborne, (1982) have reviewed the general aspects of tillage. The main objectives of tillage as understood today are:

1. Preparation of suitable seed-bed
2. Loosening the soil for improving water entry, root penetration and aeration
3. Incorporation of crop residues, manure and fertilizers
4. Elimination of undesired vegetation i.e., weed control
5. Breaking of soil crusts for better seedling emergence and water infiltration
6. Reducing of soil erosion
7. Controlling diseases and pests
8. Increase soil moisture storage for rainfed farming
9. Hastening chemical and biological activity in soil
10. Improving the physical conditions of soil

The concept of tillage requirement for crop production is changing rapidly as certain light sandy soils are adversely affected by excessive discing. Continuous tilling of some medium to heavy soils develops a hard pan at the plough sole depth, which restricts the penetration of roots and water to the sub-soil. The growing of crops with the least possible soil disturbance, which involves controlling weeds and weedicides, has given the concept of zero-tillage. More than any other tillage system, zero-tillage maintain crop residue on the soil surface, hence, it protects the surface against the wind and water erosion. However, the problem of how to eradicate weeds persistence with continuous adoption of zero tillage has yet to be solved.

As indicated by the definition and objectives of tillage operations, tillage is capable of altering the soil physical environment and crop growth. The effect of tillage on crop response depends on soil, climate, tillage, implements used, and topography. Where topsoil compaction is a problem, tillage certainly has ameliorating effects. In combined compaction-tillage experiments, Negi *et al*., (1981) found highest yields in highly compacted but subsequently chiseled or moldboard ploughed plots on both sandy and clay soils in humid climate. Uncompacted zero tilled plots were comparable. The poorest yield was on compacted zero till plots. Results obtained on both the soils showed that the yield could be expressed as a curvilinear function of soil density; however, the fit of the regression curve was poor. These conclusions were based on the average dry bulk density through the top 20 cm of the soil.

In dried regions, strategies such as zero till and conservation tillage are widely accepted as water conserving and erosion control measures and conservation tillage is generally avoided (Larson and Osborne, 1982). Even in such regions, however, tillage may be beneficial in controlling weeds or pathogens or reducing resistance to root penetration (Dann *et al*., 1987).

Bandyopadhay and Pandey, (1984) reported that deep tillage improves the soil physical properties and increased the infiltration rate. The deep tillage from 20-45 cm was found to improve capillary porosity and hydraulic conductivity. Chaudhary *et al*., (1985) reported slightly decrease in bulk density of the soil at working depth with tillage operation. Sub-soiling and deep tillage decreased the soil penetration resistance in 20-40 cm layer to $1/10^{th}$ of that in the control. Sub-soiling improved the physical conditions of the soil below the Ap horizon (Johnson *et al*., 1989). Soil bulk density was reduced by 0.50 Mg m^{-3} and pore size distribution (PSD) was altered such that the volumes of pores with radii larger than 150 µm were doubled. Pre-plant wheel traffic caused sub-soil compaction, increasing bulk density by 0.60 Mg m^{-3} and altered all indicators of soil compaction in Ap horizon, especially PSD and saturated hydraulic conductivity. The occurrence of tillage pan in sandy loam soils due to repeated tillage practices and hardening in no-tilled soils, which must be ripped by using a form of deep tillage to maximize yields. Deep tillage breakup high density soil layer, improve water infiltration and movement in soil, enhance root growth and development and increase crop production. Chambers *et al*., (1990) conducted an experiment to investigate methods of ameliorating the effect of deep compaction by a 6.4 tones axle load on a clay soil using deep tillage in combination with minimum tillage on Lucerne. Results showed that sub-soiling reduces cone resistance and bulk density of compacted and non-compacted plots. Ike and Arenu, (1990) reported that aggregate stability and porosity were less and the bulk density greater under tractor-ploughed cultivation, suggesting that more intensive cultivation increased sub-soil compaction.

Gajri *et al*., (1994) found deep tillage to reduce soil strength and enhancing rooting in coarse textured soils, whereas Surakod and Itnal, (1997) reported that the deep tillage practices has helped to open up the soil and has favoured better infiltration of rain water in soil profile compared to medium and shallow tillage practices which caused loosening of soil at the surface only. Miriti *et al*., (2013) demonstrated that maintenance of good soil porosity, infiltration and surface roughness is critical when selecting tillage systems for increased soil water conservation.

Singh and Chaudhary, (1998) reported that the tillage loosened the soil, decreased bulk density and penetration resistance to a depth of 40 cm in deep tillage plot compared to 10 cm in conventional tillage. The bulk density varied from 1.50 Mg m^{-3} to 1.56 Mg m^{-3} in the deep tillage plots as compared to conventional tillage where bulk density varied from 1.47 Mg m^{-3} to 1.70 Mg m^{-3} at 0-40 cm depth in sandy loam soils. The penetration resistance in deep tilled zone was 25 to 58 % in loamy sand and 32 to 64 % in sandy loam as compared with the untilled zone in conventional tillage. Diaz-Zorita, (1999) reported that the bulk density in the 3-20 cm layer of the soil was significantly increased from 1.14 to 1.33 Mg m^{-3} when the intensity of tillage system decreased. The deep tillage treatment significantly decreased the bulk density in no-tilled soils. Pal *et al*., (2009) revealed that deep ploughing with disc plough loosened the soil of the plough sole formed at the depth of 15-20 cm and reduced the bulk density from 1.70 to 1.56 Mg m^{-3} and in conventional tillage the reduction in bulk density was limited to a depth of 10 cm and the bulk density of plough sole remained 1.66 Mg m^{-3}. Priya *et al*., (2019) studied that soil bulk density in rotary tillage system was greater than those of conventional tillage system which indicates the existence of hard layers due to constant shallow plow at this soil depth under and suggested that some deep soil loosening tillage system combined with rotary tillage at interval of 3-4 years may be better system.

Deep tillage favoured better growth of roots and resulted in higher grain yields of rice and barley (Bandyopandhay and Pandey, 1984), millet (Compbell *et al*., 1974), corn (Chaudhary *et al*., 1985; Arora *et al*., 1991; Gajri *et al*., 1991; Singh and Chaudhary, 1998; Diaz-Zorita, 2000), wheat (Masand *et al*., 1992), sorghum (Unger, 1979; Surakod and Itnal, 1997), soyabean (Wesley *et al*., 1993), mustard (Arora *et al*., 1993; Pal and Phogat, 2004; Pal and Phogat, 2005) and sunflower (Gajri *et al*., 1997) etc.

Majority of the information on deep tillage benefits is in crops with fibrous root system e.g. corn, wheat, barley, rice, sorghum etc. but there are few reports on crops with tap root systems such as soybean, mustard etc.

CONCLUSION

The main results of our literature evaluation showed that severe soil compaction might result in a decreased root growth and plant development, and consequently, a reduction in crop yield because it adversely affects key soil hydraulic and aeration properties such as saturated hydraulic conductivity and air movement in soil. Soil productivity is very important for human survival but any form of soil degradation can reduce the soil fertility and ultimately, it lowers the soil productivity. It has attracted scientists' attention for more than a century, both on the practical and theoretical aspects. Experimental studies have shown that the soil compaction results in increase in the soil strength, bulk density, volumetric water content at field capacity, while decrease in total porosity, soil aeration, water infiltration rate, and saturated hydraulic conductivity. Soil compaction is also an environmental problem because it is one of the causes of erosion and flooding. In addition, it directly or indirectly increases nutrient and pesticide leaching to the groundwater and nitrous oxide emissions to the atmosphere. Therefore, prevention of soil compaction and alleviation of existing compaction is one of the most important issues in agricultural production in order to sustain or improve soil fertility and productivity.

ACKNOWLEDGEMENT

The author acknowledges the coauthors for the information collection, presentation and writing process.

Competing interests

There are no competing interests involved with this review.

Author's contributions

Dharam Pal designed the study and wrote the first draft of this review paper. Sunil Kumar managed the draft and aided in information collection process. All the authors played their part in reading, drafting and have approved it for final submission process.

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