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A review on compaction and loosening of agricultural soils

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Abstract

Many soil experts and farmers are very concerned about the hard soil layers of agricultural soils. A layer known as hard soil is created when soil is compacted repeatedly over a long period of time. A type of physical soil degradation known as soil hardening modifies soil structure, restricts air and water penetration, and lessens root encroachment. These effects on the crust of the earth are still not fully understood. Therefore, to solve the worldwide dilemma of future food security, a thorough understanding of the subsurface processes is required. Compaction research must also be taken seriously because climatic conditions are shifting as a result of climate change, opening the door for the creation of novel mechanical tillers that can address compression problems. As a result, the focus of this study is on investigating the type, traits, causes, and effects of soil compaction on agricultural production as well as potential remedies using soil tillage.

Keywords: Compaction; Hard pan; Agricultural soils; Subsoiler; Soil structure

1. Introduction

A major issue and pressure on land use continues to come from the geometric rise of the world's population, the need to meet high food demands, and economic development, particularly in emerging nations.is expanding, making industrial-scale commercial agriculture the way to meet food needs. Additionally, in order to boost net profits in the near term, global intensive agriculture has been given priority, which includes shorter crop rotations, monocropping systems throughout the seasons, and the use of large machinery possible. In order to attain desirable soil conditions, heavy tillage equipment is used in land intensification for agricultural reasons, which includes the intensification of crops and consequent overexploitation of the land.

Compaction of the soil can result from large-scale plow operations on freshly plowed land (Reichert et al. 2009). If the load from automobile traffic destroys the soil's pore structure both during compaction and shear, then there has been compaction. Agriculture systems research has long sought to enhance conventional and conservation tillage methods in an effort to lessen the damaging pressures connected to intensive agricultural systems, which can have a detrimental effect on crop output. Prior to soil compaction, the change in pore size distribution causes unstable soil particle consolidation (Kulkarni et al. 2010). The development of soil macropores can also be controlled by the farming practices used and field traffic.

Furthermore, Godwin et al. (2019) discovered that frequent transportation operations on land, particularly on farming, can demolish surface and subsurface infrastructure. The mineralization of soil organic carbon, nitrogen, and carbon dioxide is also impacted by poor soil aeration (Abu-Hamdeh, 2003). The causes of soil compaction, the impact of compaction indices on the health of the soil and crop performance, and possible solutions are all covered in this paper.

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There are numerous research on soil compaction, its causes, and how to decrease it using various ways. However, some of them provide remedies for soil compaction utilizing mechanical equipment, with a focus primarily on the compaction effect of agricultural machinery on agricultural land. The review of compaction procedures provided by this paper is crucial, particularly the methods for releasing subsoil using mechanical tools like hard shears.

2. Soil Compaction Indicators

2.1. Soil moisture

According to Wu et al. (2008), soil moisture has the greatest impact on the likelihood of soil compaction. The soil has the highest capacity for compaction when its moisture content is equal to or greater than the field's compressive capacity. when water is used in place of air. Above this degree of soil saturation, water cannot crush the soil, reducing the topsoil's ability for compaction. The risk of subsoil compaction is raised as a result of the direct transmission of compaction pressures into the ground (Han et al., 2009). Additionally, the spreading of topsoil that occurs when very moist soils move might be even more harmful to plant root growth than compaction because it lowers hydraulic conductivity (Raper and Kirby, 2006).

2.2. Soil texture and structure

The ability for compaction is somewhat influenced by soil texture. According to Arvidson and Keller (2007), soils with particles of varied sizes are less compressible than soils with particles of same size. Pure sandy loams, clays, and loams are the least prone to compaction, while sandy loam soils as a whole are (Millington et al 2016). While compaction in finer textured soils tends to extend horizontally down and outward into the profile land, compaction in coarser soils tends to extend vertically down the soil profile. Soil structure also affects compactability. Aggregates are created by natural soil processes as wetting and drying, freezing and thawing, as well as bacterial, fungal, and root growth (Shaheb et al., 2020).

An essential defense against soil compaction is provided by soil structure. In comparison to soils with less organic matter, soils rich in organic matter frequently have superior structure and are more compression resistant (Shaheb et al., 2018). The three main factors that degrade soil aggregates are tillage, precipitation, and compaction. Due to the destruction of soil aggregates, plow operations that combine shearing action with significant downward pressure produce the most damage to soil structure (Wolkoski et al., 2008). These operations also have a tendency to form plow pans at the bottom of the plow layer.

2.2.1. Bulk density and porosity

Although bulk density is the most widely used metric to define soil compaction (Whitemore et al. 2011), it is advised to measure bulk density at standard moisture content for swelling/shrinking soils (Shahab et al. 2021). While the stress state transducer with six soil pressure gauges monitors the stress in deeper layers, the new resistance indicators are exceptionally accurate for measurements of soil density up to 20 cm deep. Power in three dimensions might be advantageous (Hoad et al., 2001). According to Ale and Manuwa's (2011) findings, bulk density and penetration resistance both rose with depth but there was no discernible relationship between the two. In gravelly soils, bulk density is challenging to estimate (Spoor et al., 2006). Soil bulk density alone is insufficient to fully assess the effects of soil compaction on all types of soil; other soil characteristics, such as soil strength, soil aeration, and soil aeration, must also be assessed. Moisture in the soil (Hoeft et al. 2000).

3. Compaction Detection and Measurement

3.1.1. Crop symptoms

Root development that is not properly formed might result from compacted soil. In soil boxes, roots may develop a shallow, flat root system rather of developing vertically (Well et al 2005). Underground root growth is intimately correlated with aboveground growth. Vegetative growth above ground will probably slow down if root growth is compromised. These zones could be the outcome of numerous instances of the same region being overlapped with varying tillage times over time, which eventually has a cumulative effect on different parts of the field. Another indication of compaction can be nutrient stress on plants (Alameda et al. 2012).

3.1.2. Soil Symptom

Soil compaction may result in standing water or excessive water erosive processes. Because of the reduced interstitial space caused by compaction, water cannot be absorbed into the soil as readily.

Compaction may also be indicated by increased energy requirements for field work (Voorhee et al., 2000). The presence of tillage activities in some fields where the tractor is "going down" may be a sign of compaction occurring there.

4. Measuring Soil Compaction

With a shovel or other form of excavator, sidewall compaction, surface crust, and tillage trays are the most straightforward to find. Due to its deeper location in the soil, deep soil compaction is more difficult to detect. Cone penetrometers can be used to locate the compression, although they have limits (ASABE, 2018). It is necessary to compare soils with and without compaction that are the same moisture content and texture. As a result, compressibility cannot be measured using a specific numerical strength (psi) value (ASABE, 2013). A different useful tool is a soil detector, and this also rely on the density and wetness of the soil.

5. Compaction and Tillage Operational Parameters

5.1.1. Tractor forward speed

When combining a tractor and an implement, field speed is a crucial consideration. The ideal travel speed for various tasks is between 6 and 9 kilometers per hour (9. 4 to 12 miles per hour). This is so because the majority of tools are made to work this quickly and effectively. Operating speed consequently has a large impact on the bulk density and hydraulic conductivity values of the soil.

According to Abd-Razzak Jasim et al. (2015), hydraulic conductivity decreased and soil bulk density increased as operating speed increased. For all plantation growth phases, operating speed increased from 3. 69 to 4. 23 and 11. 17 km/h-1, reduced hydraulic conductivity, and increased soil bulk density values.

5.1.2. Fuel Consumption

Fuel usage while tilling is a relative factor. The energy input per unit of soil material is expressed as fuel consumption per mass of soil moved. At a depth of 35 cm, the amount of diesel consumed increased from 12.8 l/ha at a depth of 18 cm to 18.3 l/ha. On the other hand, the amount of energy used to move each ton of soil dropped from 584 Wh/t to 429 Wh/t. This result is brought on by the "basic" consumption drifting away as the amount of land moved increases. For heavy planting, the "basic" consumption is 5. 4 l/ha for heavy planting and 7. 9 l/ha for plowing. It is unclear whether a heavy cultivator will result in a lower energy consumption per ton of loose soil than a plow due to the varied operating depths (Kuma et al., 2020).

5.1.3. Draught and Power Requirement

Conventional tillage is defined as "primary and secondary tillage operations commonly carried out to prepare seedbeds and cultivate a given crop to be grown on a given area, usually comprising 30% crop residue left on the surface after completion of the tillage sequence" (SSSA, 1997; Koller, 2003). This tillage strategy is used for a variety of purposes, including burying weed seeds to help with weed control, maintaining productivity, achieving a residue-free soil surface that encourages seedling establishment, and combining fertilizers and herbicides as well (Koller, 2003).

However, this kind of rigorous plowing requires a lot of energy, and the exposed soil surface that results from these operations is prone to erosion. As a result, a lot of study has been done, and the literature shows how tillage techniques that keep residue on the soil surface and reduce or eliminate reverse tillage can maintain and boost productivity. Increasing soil quality while increasing agricultural yield.

5.1.4. Types of soil compaction and causes

Soil compaction can take many different forms during agricultural production and has a detrimental effect on crop growth and yield. Although other types of compaction, such as sidewall and surface skin compaction, can drastically lower yield under certain circumstances, they typically present less management challenges because they typically do not persist long in the soil and can be handled in a variety of ways, and alternatives are available to either prevent or lessen their impact.

Tillage beds and subsoil compaction are two more types of compaction that can last for many years and are significantly more challenging to manage. Several agricultural practices can result in agricultural soil compaction. Excessive tillage leading to the dissolution or degradation of soil surface aggregates, removing protective residues from the soil surface, exposing the soil to natural environmental pressures, and so on (Liu, 2021). The soil may develop a crust as a result, hardening and compacting the topsoil. Particularly when the soil is wet, tillage tools can also compact the soil slightly below the tillage depth. According to Millington et al. (2019), this sort of compaction is also referred to as hard layer or plow layer. Wheel compaction in the root zone can occur to a great depth due to the weight of heavy agricultural equipment (tractors, seed trucks, combines, trucks, and manure spreaders) (Hassan et al., 2007). The depth of soil compaction also rises when soil moisture rises.

5.2. Effects of compaction on soil and crop growth

According to Hatley et al. (Hatley et al. 2021) heavy equipment in the field or tillage equipment used during tillage are the main causes of soil compaction. To obtain a smaller volume, soil particles may move closer to one another as a result of soil compaction (Hassan et al. 2007). The amount of space that is accessible for air and water in the soil is reduced when particles are crushed close to one another.

Reduced soil voids, slower water infiltration into the soil, slower water penetration into the soil's root zone, increased risk of surface water stagnation, runoff, surface waterlogging, and soil erosion, and decreased soil's capacity to retain water and air essential for plant root growth are just a few of the detrimental effects of soil compaction on soil quality and agricultural production.

Compaction hinders plant growth, limits the amount of soil roots can explore, and prevents roots from penetrating the ground. Limited root exploration also reduces a plant's ability to efficiently absorb nutrients and water from the soil. Compaction also causes soil aggregates to be crushed. Increased plant stress and yield loss are the results of each of these conditions.

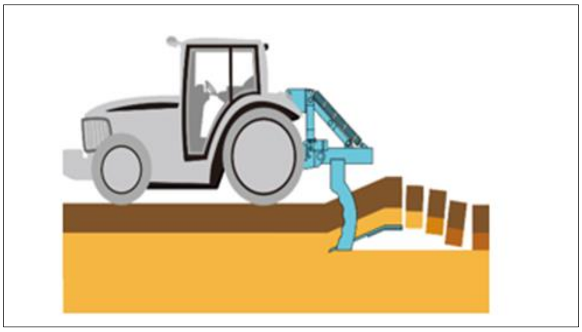
6. Relationship between Soil Compaction and Farm Machinery Use

Increases in bulk density or decreases in porosity brought on by external factors like: impact of raindrops, soaking of the soil, and water tension in the soil (Raper et al.200). Due to contact with the tires or tracks of tractors and other agricultural machinery, artificial compaction plays a significant role and actually influences the environment for plant growth (Shaheb et al., 2021). Compaction decreases the soil's ability to retain water, which causes runoff to produce ideal circumstances for soil surface erosion and improper soil moisture recovery. Equations that account for the forces that generate compression must be used to mathematically describe it. This viewpoint proposes two primary categories of forces: The mechanical forces produced by machinery and animals come first. These forces are applied during brief times and are relatively simple to quantify. Natural phenomena are included in the second category of force. For instance, soil compaction is impacted by drying. Long-lasting and challenging to define and measure, the second category of forces operate over extensive time frames. Only accurate equations that precisely characterize the compaction properties of the soil can be used to estimate how much the soil has been compacted.

7. Existing Hardpan Breakers

7.1.1. The "Cut Breaker" Subsoiler

In contrast to a standard backhoe, the shovel crusher (backhoe) shown in Figures 1a–d can access and break up deeper compacted soil layers. In fact, a layer of hard soil is typically created by plow use at a depth of 15 to 30 cm. This causes a hard soil layer that is characterized by compaction of the soil layer beneath the soil surface, which prevents plant roots from moving freely in the soil (Baumhardt, 2003). Additionally, water traveling along the soil profile will stagnate and create ponds when it reaches the hard basin area, and the soil will turn salty (Chen et al., 2004). As a result, in order to address the issue of hard pans, hard pan cutters must be created. It provides a fix for fields with bad drainage brought on by compacted soil. The single to triple V-shaped blades assist cut the soil to a depth of 30-70 cm and break up the hard soil. It is powered by a tractor or coupled to a bulldozer. Up to three rows of crushed earth are produced, each up to 80 cm broad at the top and 10 cm wide at the bottom. Higher yields and sustained agricultural production are the results of improving the soil with "Cut Breaker" (NARO, 2020).



Source: NARO, 2020

Figure 1a The "Cut Breaker" Subsoiler

Figure 1b How the Cut Breaker Works

The Source: NARO, 2020

Figure 1c Bottom Hydraulic Reversible

Figure 1d Plough Rotary Cultivators

Additionally, by fracturing the hard soil layer, water and nutrients will be able to penetrate far into the soil, where they will be sustainably retained over time by microorganisms. Plants will be able to access moisture and nutrients in the soil during droughts if they are consistently available. Utilizing a cultivator to till the soil encourages the life processes of soil organisms, which in turn improves soil structure and porosity and raises the proportion of humus in the soil.

8. Conclusion and Recommendation

The worst sort of land degradation that reduces agricultural output is soil compaction. Numerous elements, including as tillage techniques and heavy mechanical loads, contribute to soil compaction, and the resulting pressures have caused soil quality to shift as a result of evolving practices physics and chemistry of soil. In addition to these consequences, soil compaction lowers crop productivity by influencing plant growth and development. The main morphological impacts of soil compaction are slow development, leaf discolouration, lower plant height, and shallow root systems, while poorer nutrient absorption and reduced leaf gas exchange, Carbon assimilation, and reduced photosynthetic activity all occur. Soil compaction has detrimental impacts on translocation that call for careful analysis and a remedy. In order to simultaneously break up the compacted hard layer and complete the harrowing duty in a single operation, it is advised that shovels and soil crushers with tools be designed and developed work. The creation of this kind of machine will also contribute to a decrease in the amount of agricultural equipment that is constantly traveling across agricultural land.

Compliance with ethical standards

Disclosure of conflict of interest

Authors declare that there is no conflict of interest

References

[1] Ale, M. O. and Manuwa, S. I. 2011. Penetration resistance and Hydraulic conductivity of soil under intensive and continuous usage in Akure, South-western Nigeria. Proceedings of Nigerian branch of international soil tillage research organisation held in February, 2011 in Ilorin, Nigeria.

[2] Arvidsson, J., & Keller, T. (2007). Soil stress as affected by wheel load and Tyre inflation pressure. Soil and Tillage Research, 96(1), 284–291. https:// doi. org/ 10. 1016/j. still. 2007. 06. 012

[3] ASABE Standards. (2013). ASAE EP542 FEB1999 (R2013). Procedures for using and reporting data obtained with the soil cone penetrometer. American Society of Agricultural and Biological Engineers (ASABE). St. Joseph, MI.

[4] ASABE Standards. (2018). ASAE S313.3 Feb 1999 (R2018). Soil cone penetrometer. American Society of Agricultural and Biological Engineers (ASABE). St. Joseph, MI. Retrieved from https:// elibrary. asabe. org/ pdfvi ewer. aspx? GUID= 0D485 B88- 5E54- 46E5- 8296- C99F3 36B62 8D

[5] Baumhardt L. Dust Bowl Era. Encyclopedia of Water Science 2003. Available from: https://www.baymeadowscharter.org/ourpages/auto/2019/9/16/54520179/Lithosphere%20KQ4_%20Dust%20Bowl%20Case%20Study.pdf

[6] Chen, Y., Cavers, C., Tessier, S., Monero, F., Lobb, D. (2004). Short-term tillage effects on soil cone index and plant development in a poorly drained, heavy clay soil. Soil and Tillage Research, 82:161-171

[7] Godwin, R., Misiewicz, P., White, D., Dickin, E., Grift, T., Pope, E., Dolowy, M. (2019). The effect of alternative traffic systems and tillage on soil condition, crop growth and production economics - extended abstract. In TAE 2019 - Proceeding of 7th International Conference on Trends in Agricultural Engineering, Prague, Czech Republic, September 17-20, 133–134.

[8] Han, S. K., Han, H. S., Page-Dumroese, D. S., & Johnson, L. R. (2009). Soil compaction associated with cut-to-length and whole-tree harvesting of a coniferous forest. Canadian Journal of Forest Research, 39, 976–989. https:// doi. org/ 10. 1139/ X09- 027

[9] Hassan, F. U., Ahmad, M., Ahmad, N., & Abbasi, M. K. (2007). Effects of subsoil compaction on yield and yield attributes of wheat in the sub-humid region of Pakistan. Soil and Tillage Research, 96(1–2), 361–366. https:// doi. org/ 10. 1016/j. still. 2007. 06. 005

[10] Hatley, D., Wiltshire,J., Basford, B., Royale, S., Buckley, D., & Johnson, P. (2005). Soil compaction and potato crops. Research review (Vol. R260). Oxford, UK. Retrieved from http://www.potatoes.ahdb.org.uk/sites/default/files/publication_upload/R26

[11] Hoad, S. P., Russell, G., Lucas, M. E., & Bingham, I. J. (2001). The management of wheat, barley, and oat root systems. Advances in Agronomy, 74, 193–246. https:// doi. org/ 10. 1016/ S0065- 2113(01) 74034-5

[12] Horn, R., Way, T., & Rostek, J.(2003). Effect of repeated tractor wheel-ing on stress/strain properties and consequences on physical properties in structured arable soils. Soil and Tillage Research, 73(1–2), 101–106. https:// doi. org/ 10. 1016/ S0167- 1987(03) 00103-X

[13] Millington, W. A. J. (2019). The effect of low ground pressure and controlled traffic farming systems on soil properties and crop development for three tillage systems. Ph.D. thesis. Harper Adams University, Newport, Shropshire, United Kingdom.

[14] Millington, W. A. J., Misiewicz, P. A., Dickin, E. T., White, D. R., & Godwin, R. J. (2016). An investigation into the effect of soil compaction and tillage on plant growth and yield of winter barley (Hordeum vulgare L.). In 2016 ASABE Annual International Meeting, Orlando, 17-20 July, 1901979, 1–12, St. Joseph, MI. https:// doi. org/ 10. 13031/ aim. 20162 461725

[15] Raper, R. L. (2005). Agricultural traffic impacts on soil. Journal of Terramechanics, 42(3–4), 259–280. https:// doi. org/ 10. 1016/j. jterra. 2004. 10. 010

[16] Raper, R. L., & Kirby, J. M. (2006). Soil compaction: How to do it, undo it, or avoid doing it. Agricultural Equipment Technology Conference, 913, 1–15.

[17] Rickson, R. J., Deeks, L. K., Corstanje, R., Newell-Price, P., Kibble-white, M. G., Chambers, B., Waine, T. (2012). Indicators of soil quality - Physical properties (SP1611). Final report to DEFRA. Cranfield University and ADAS, UK. Final report to DEFRA. Cranfield University. Cranfield, UK, 1–45. http:// randd.defra. gov. uk. Retrieved from http:// randd. defra. gov. uk/Default. aspx?Module=More&Location=None&ProjectID=17595.

[18] Shaheb, M.R., Grift, T. E., Godwin, R. J., Dickin, E., White, D. R., & Misiewicz, P. A. (2018). Effect of tire inflation pressure on soil properties and yield in a corn - soybean rotation for three tillage systems in the Midwestern United States. In 2018 ASABE Annual International Meeting, Detroit, 29 July–01 August, 1801834, 1–14. St. Joseph, MI. https:// doi. org/ 10. 13031/ aim. 20180 1834

[19] Shaheb, Md Rayhan, Klopfenstein, A., Tietje, R. W., Wiegman, C. R., Dio, C. Di, Scarfagna, A., Shearer, S. A. (2021). Evaluation of soil-tire interface pressure distributions and areas resulting from various tire and track technologies and configurations. In 2021 ASABE Annual International Meeting, 12-16 July, 1–11. St. Joseph, MI. https:// doi. org/ 10. 13031/ aim. 20210 0889

[20] Spoor, G. 2006. Alleviation of soil compaction: requirements equipment and techniques. Soil Use and Management, 22, 113–122.

[21] Spoor, G., Tijink, F.J.G. & Weisskopf, P. 2003. Subsoil compaction: risk, avoidance, identification and alleviation. Soil and Tillage Research,73, 175–182

[22] Voorhees, W. B. (2000). Long-term effects of subsoil compaction on yield of maize. Advances in GeoEcology, 32, 331–338. Retrieved from https:// www. cabdi rect. org/ cabdi rect/ abstr act/ 20013 087603

[23] Wells, L. G., Stombaugh, T. S., & Shearer, S. A. (2005). Crop yield response to precision deep tillage. Transaction of the ASAE, 48(3), 895–901. https:// doi. org/ 10. 13031/ 2013. 18493

[24] Whitmore, A. P., Whalley, W. R., Bird, N. R. A., Watts, C. W., & Gregory, A. S. (2011). Estimating soil strength in the rooting zone of wheat. Plant and Soil, 339(1), 363–375. https:// doi. org/ 10. 1007/ s11104- 010- 0588-7

[25] Wolkoski, R., & Lowery, B. (2008). Soil compaction: Causes, concerns, and cures. University of Wisconsin-Extension, Cooperative Extension, A3367 Retrieved from http:// www. Soils. wisc.edu/ exten sion/ pubs/ A3367. pdf

[26] Wu, X., Tang, Y., Li, C., McHugh, A. D., Li, Z., & Wu, C. (2018). Individual and combined effects of soil waterlogging and compaction on physiological characteristics of wheat in southwestern China. Field Crops Research, 215, 163–172. https:// doi. org/ 10. 1016/J. FCR. 2017. 10. 016