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Review Article

Controlled Traffic Farming: A Sustainable Solution to Soil Compaction

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Abstract

Sustainable agricultural production aims to feed and fuel for increasing population. The use of advanced heavy farm machinery has enhanced the efficiency of agricultural operations and food production since many decades. But on the other part, these machines are affecting soil health causing the soil compaction. About 68 million ha of land worldwide has been affected with soil compaction. Wheel traffic induced soil compaction increases soil bulk density, Consequently, affect nutrient mobility and soil gaseous fluxes, crop/root growth, crop productivity, yield and economics. Controlled traffic farming (CTF) is a one of the sustainable solutions to overcome the soil compaction or prevent the further soil compaction. CTF separates the wheel traffic lane from the cropping zone and may be resulted in less than 30% area under traffic lane. Research confirms the positive effects on agricultural production and soil health worldwide. In this article we discuss about the soil compaction, its causes, adverse effects and CTF system in terms of trafficked area, soil health, environment and economic sustainability.

Keywords: Soil Compaction, Wheel Traffic, Controlled Traffic Farming,

Introduction

The world is currently facing many challenges includes ensuring food security, minimizing environmental damage, and ensuring sustainable agriculture production. The introduction and use of farm machinery have reformed farm production and contributed in improved productivity and sustainability. Regardless of the benefits of saving time, money and labor required for the operation [10], heavy farm machinery resulted into substantial compaction of soil that could disturb the soil structure and ultimately affect crop growth and production [8,16,24,34]. The increase in use of farm machinery and increased weight of farm machinery plays important part in enhancing wheel traffic induced soil compaction in many regions of the world [17,20]. About 68 million ha of land worldwide has been affected with soil compaction [28] (Figure 1), which could rise potentially in the coming years.

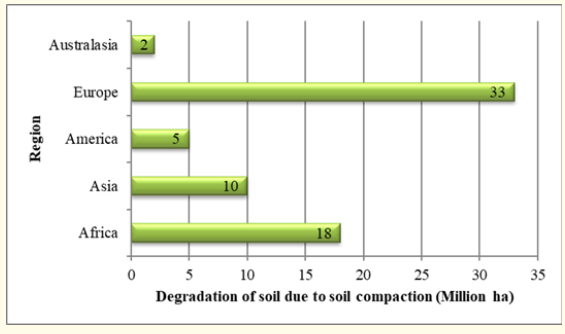

Figure 1: Degradation of agricultural land due to soil compaction in different regions (Adopted from Oldeman, 1992 [28]).

Soil compaction is the process encouraged by wheeling of mobile farming units, by which the soil grains are rearranged to decrease void space and bring them into closer contact with one another to increase bulk density [15,40]. Consequently, affect nutrient mobility and soil gaseous fluxes, crop/root growth, crop productivity, yield and economics [3,17,20,31,34,35,41]. The brief overview of the soil compaction including types, different causes and effects is presented in figure 2.

The several studies have been shown that the soil compaction caused mainly due to compressive forces applied to soil from wheels under tractors, trailers and harvesters, during the passage

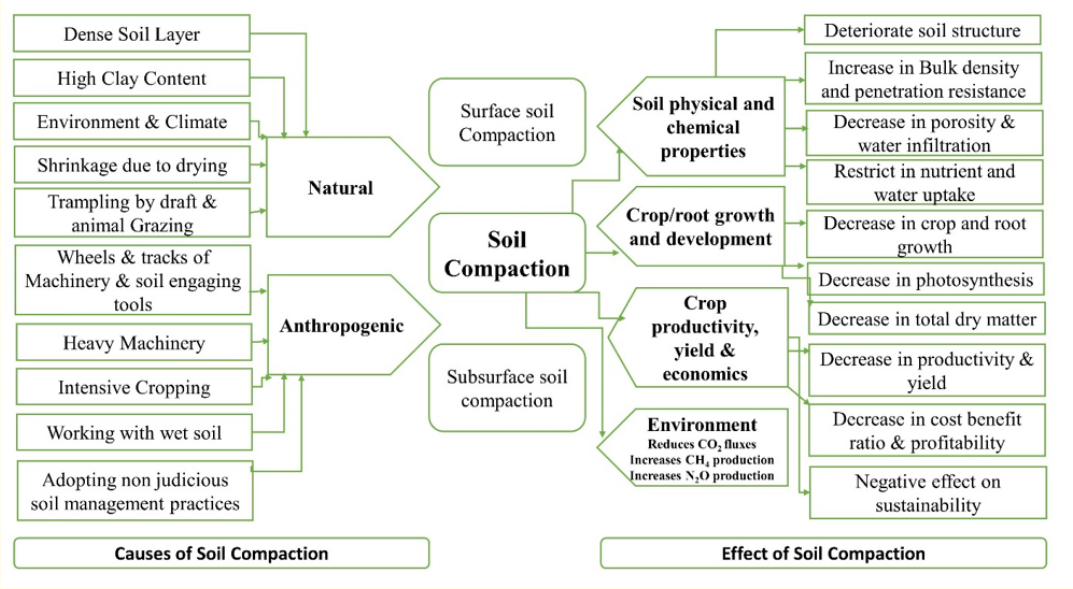

Figure 2: Overview of soil compaction.

of tillage implements and from pressure under the hooves of livestock or other animals [3,9,27,34,35]. There are two types of soil compaction i.e., surface compaction and subsurface compaction. Both are correspondingly substantial in the study of soil compaction and management [34]. In the surface soil compaction, the upper layer of the soil up to a depth of 15 cm is compacted in the form of soil crust. Surface soil compaction occurs due to pressure exerted by the tire, track or the animal hoof. In the subsurface soil compaction, the subsurface soil gets compacted in the form of hard pan (plough pan) below the surface due to repeated tillage/soil manipulating operations with heavy machineries. It occurs from excessive pressure imposed by vehicle load [21,34].

Soil compaction increases bulk density of soil, reduces pore space, increases penetration resistance and degrade the soil structure. Soil biota get affected due to soil compaction such as decreased earthworm numbers; slower water infiltration and percolation, stunted root growth, reduced uptake of immobile nutrients and increased nitrogen losses which directly affect the yield and production of the agriculture. Also, the subsoil compaction persists over a long period and it is very costly to eliminate. Thus, there is a need of such technology which limit the soil compaction. Several scientists reported different techniques to reduce or prevent the soil compaction such as use of high flexion tires/tracked vehicles [7,14]; use of predetermined wheel ways to run equipment (Controlled traffic farming) [2,13,44]; to reduce the weight of machinery/wheel load/axle [3,5,15,34]; Deep ripping/Subsoiling/chiseling to break the subsurface hard pan [1,5,34,37]; conservation tillage [11,31] and other agronomic practices such as crop rotation with deep tap rooted crops [8,19]; Mulching/straw mulching to increase organic matter in the soil [36] etc. All the techniques have their own pros and cons.

Controlled traffic farming (CTF)

It is possible to prevent soil compaction by directing machinery traffic in a way that eliminates compaction by placing machinery traffic pathways, controlling axle loads, tires and inflation pressure, and controlling soil conditions under which wheel traffic is allowed. CTF is one of the approaches which can restrict the field traffic to the permanent tracks and that can be maintained year after year [25,44]. CTF is the wheel traffic management technique for agricultural lands to reduce soil compaction formed due to wheel traffic [32]. As a result of CTF, natural processes can repair affected soil and prevent further deprivation of the soil. After years of CTF practice, full restoration of natural conditions of soil may be possible [23,44].

CTF is a farming system in which the traffic lanes across the land has been confined and separated from the cropping zone [42]. It means that the machines used in the field can be travel through the same track with navigation aids or autosteering systems [32] or conventional marking system. Therefore, CTF prevents the wheels from damaging the crop zone, while the wheel traffic lanes are compacted and drought efficiency is improved [43]. Appropri-

ate agronomical and crop management practices can enhance the potential of cropped as well as wheel trafficked areas for their specific purposes.

In practice, CTF means the repetitive use of the same wheel track for performing each field operation like sowing/planting, spraying, trailing, harvesting etc. Equal wheel track and particular span (base module) for all machines can be an ideal condition but it is not essential. The wheel trafficked area can be reduced to 30-40% even with two different wheel track and implement span/width. Figure 3 shows the CTF common module for different width machineries i.e., planter, harvester, trailers and chemical applicator [6].

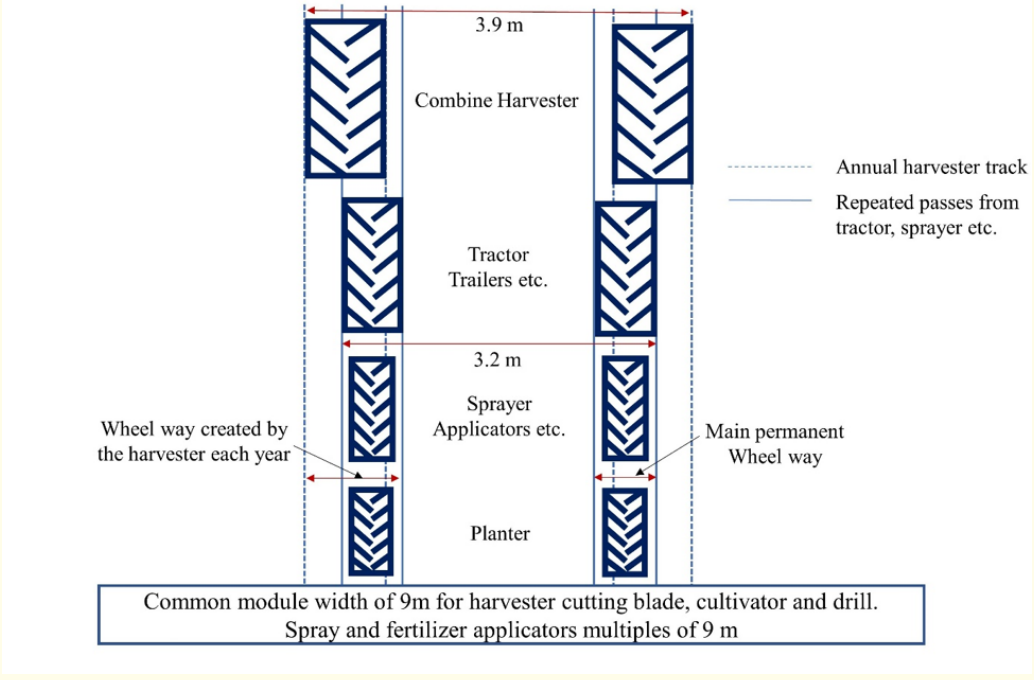

Figure 3: Common module for different width implements/machineries (adopted from Chamen et al., 2003 [6]).

CTF is the system suitable for anyone related to agriculture. It is suitable for any crops, whether these are cereals, legumes, vegetables, grasses, energy and roots on small as well as large commercial scale with variety of systems such as manual, semi or highly mechanized cropping systems. This system can save inputs at their sources and it creates different opportunities by avoiding compromises related to the traffic induced soil compaction [29].

Benefits

CTF has various benefits and they all help to bring increased profit along with improved sustainability in farming operations [46]. These are delivered by improving soil health, result in lower costs and higher returns along with improved environmental conditions.

Trafficked area

Wheel traffic area has been reduced in CTF system as compared to conventional traffic practices. Random traffic farming (RTF) in conventional practice in one season, creates 80-100% trafficked area of the total field with conventional tillage practices, while 30-60% with reduced and zero tillage practices [30,38,39,44]. As compared to these practices, CTF only cause 10-20% wheel trafficked area of the total field [39,45,47].

Soil health

The CTF system reduces the trafficked area to less than 30% of total field area and increases the cropping area. Confined wheel trafficked area, causes soil compaction at that confined area without affecting the cropping area. Hence, it improves the health of the soil at cropping zone. The physical properties of soil, water movement in the soil, pore spaces, bulk density has been improved and this facilitates the improved root growth and crop growth ultimately resulted into high yield. CTF also improves the micro flora and fauna in the soil, microbial activity and organic carbon. It also decreases the runoff and the soil erosion and enhances efficiency of fertilizers and chemicals applied [32,44].

Crop growth and yield

Improved soil health due to CTF provide essential nutrients, water and organic carbon to the crop resulting into enhanced crop quality and increase grain yield by 2-16% with less input cost. CTF also improves the micro fauna in the soil which helps crop for its proper growth.

Environment

The CTF system has been reported to provide many environmental benefits such as reduced risk of greenhouse gasses emissions such as nitrous oxide and methane, enhanced carbon sequestration, reduce soil erosion losses, water runoff losses [12]. The less carbon dioxide emission from the CTF farm has been reported due to less consumption of fuel for operating on a permanent wheel track and reduced tillage practices. Nitrous oxide and methane formation may be less in a CTF cropping system compared to conventional practice. The good condition of CTF soils, if subsoil constraints have been fixed properly, improves infiltration of large rainfalls and can minimize run-off and ultimately the erosion. With these environmental benefits, the carbon footprint of CTF is likely to be the lowest of all farming systems.

Economics

The CTF system use the inputs i.e. seeds, fertilizers, chemicals etc. precisely, hence lower the usage and ultimately the cost. Also, this system reduces the tillage practice and compacted tracked lane supports smooth working of the machineries which resulted into optimized fuel consumption and enhances life of tractor and other machineries. Tullberg., *et al.* 2007 [44] has been reported that the CTF system reduces the fuel cost up to 50% and spraying cost up to 10%. Similarly, Webb *et al.,* 2004 [48] reported the reduction in input cost up to Rs. 6000/ha.

Constraints for adoption of CTF

Although there are many factors that have encouraged the adoption of CTF, there are also constraints for it (Figure 4). The major constraint is that the CTF need more planning and discipline and it could lessen the devising ways of enhancing the field efficiency [4]. The minor constraints include disbelief of the farmer that the change can be happen with the CTF adoption and the community only thinks about the obstacles rather finding the solutions. Lack of appropriate machinery for CTF system and its higher cost are another issue limiting farmers to think about the CTF adoption [33]. At this time, CTF adoption depends on existing equipment or its modification. The mismatch between the wheel track widths for this equipment is the major concern for adoption. Along with these constraints, perceptions of the farming that CTF is not suitable for the small farms are holding back the farmers from taking the advantage of CTF system [22,41].

Figure 4: Constraints for the adoption of CTF.

Controlled traffic farming in India

Indian agriculture is characterized with land fragmentation with majority of small and marginal land holdings (>86%). The average farm size is reported to be less than 1.08 ha. Less than 1% share of total operational holdings were belonging to large farmers during 2015-16. Presently, some of the farmers from this group only could use CTF for their crop production field which is less than 1%. Hence, there is a vast scope for development and adoption of this practice in Indian agriculture.

The agricultural mechanization is at early stage in India and growing at 7.5% per annum in spite of the challenges of small land holdings, cropping pattern, varied soil, topography etc. [26]. The increased population of tractor, power tillers, combine harvesters indicate the increasing trend of the mechanization level in Indian agriculture. This increasing mechanization level in agricultural field contribute in enhanced production, productivity and profitability by achieving timeliness of operations, increased input use efficiency and reducing unit cost. Undoubtedly, these technologies

made the agriculture profitable in India for various farm operations. However, the continuous use of these machineries in the field has resulted into the soil degradation and subsurface compaction of soil along the wheel tracks of tractors and other heavy machineries. Though the mechanization in India is at early stage, there is a vast scope of CTF to prevent soil compaction and to deal with present soil compaction.

Adoption of this sustainable system is beneficial for the farming community. The adoption of CTF requires many efforts in extension, awareness, region and crop oriented research data base, policy interventions for convincing farming community and policy makers at local level. The most of the research available on CTF have been confined to the developed nations, no studies from India has been reported from India.

Conclusion

Limiting the wheel trafficked area in the field leads to lowering the soil degradation and compaction. Wheel trafficked soil compaction has many consequences in terms of soil degradation, nutrient uptake, water movement, energy and crop yield etc. The changing technologies and management techniques are now allowed us to tackle with this artificially created situation. CTF is the simple management system which separate out the wheel traffic lane from cropping area into a least possible area. Least wheel traffic lane resulted into fixed soil compaction zone at that particular area (< 30%) without affecting cropping zone. CTF system reduces soil compaction, improves soil health, reduces the input cost, enhance the crop productivity and yield and reduces greenhouse gas emissions to the environment. Though there are many benefits with CTF system, the adoption level is less due to the lack of awareness, lack on suitable technology, guidance, lack of suitability research in particular region, higher cost etc. There are many opportunities for researchers and engineers to support the development of efficient system and machineries for CTF system.

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