Review Article
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Conservation tillage: impacts on soil physical conditions–an overview

Abstract

Farming systems today have more obvious and detectable social, ecological, economic and environmental implications than ever before because of the growing concerns about agricultural sustainability and the environment. Tillage, basic & important component of agricultural production technology influences agricultural sustainability through its effects on soil processes, properties and crop growth. The conventional soil management practices resulted in losses of soil, water and nutrients in the field, and degraded the soil with low organic matter content and a fragile physical structure, which in turn led to low crop yields and low water and fertilizer use efficiency. It is therefore essential to select a tillage practice that sustains the soil physical properties required for successful growth of agricultural crops. Conservation tillage (CT) in its many and varied forms like zero tillage, stubble mulch tillage, etc., holds promise for the sustainability of agricultural productivity and the environment by reducing production costs, preserving soil quality, reducing herbicide and weeding labour input costs and greenhouse gas emissions. Conservation tillage improves soil aggregate stability that enhances nutrient retention and reduces soil erosion thereby contributing to soil fertility and mediates air permeability, water infiltration, and nutrient cycling. CT is particularly important in arid and semi-arid zones, where water is the limiting factor for crop development and thus correct management of crop residues is essential to achieve sustainable yields. CT with mulch improved the soil porosity, soil structure, and water transmission in alfisols and more continuous pore system because of earthworm activity, long root channels etc.. However, the adoption of particular tillage system for an area must consider the soil and climate condition for a given crop and thus, tillage indices under soil diverse conditions may provide such guidelines.

Keywords: conservation tillage, sustainability, stability, physical properties

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Introduction

Public awareness about the state of our environment is growing worldwide. Recently, several reports have been published to highlight the importance of soil quality in achieving sustainable farming systems, which attempt to balance productivity, profitability and environmental protection and environmental protection. The greatest challenge to the world in the years to come is to provide food to burgeoning population, which would likely to rise 8,909 million in 2050. The scenario would be more terrible, when we visualize per capita availability of arable land. The growth rate in agriculture has been the major detriment in world food production. It has been declining since past three decades. The rapidly expanding global population and its pressure on the finite amount of land available for agricultural production; maintaining soil quality is essential not only for agricultural sustainability, but also for environmental protection. Maintenance of soil quality would reduce the problems of land degradation, decreasing soil fertility and rapidly declining production levels that occur in many parts of the world which lack the basic principles of good farming practices. The cultivation of agricultural soils has until recently predominantly been achieved by inverting the soil using tools such as the plough. Among different operations, the soil tillage is considered one of the most important practices in agricultural production due to its influence on physical, chemical, and biological properties of the soil environment. An important effect of soil tillage on sustainability is through its impact on the environment e.g. soil degradation, water quality, emission of greenhouse gases from soil-related processes, etc.

Tillage is a labour-intensive activity in low-resource agriculture practised by small landholders, and a capital and energy-intensive activity in large-scale mechanized farming.[1] The conventional soil management practices resulted in losses of soil, water and nutrients in the field, and degraded the soil with low organic matter content and a fragile physical structure, which in turn led to low crop yields and low water and fertilizer use efficiency.[2] Conventional soil management practices resulted in degradation of the fertile soil with low organic matter content and a fragile physical structure, which in turn led to low crop yield, low water and fertilizer use efficiency. Conventional tillage overturns the soil layer, which breaks the structure of soil and as a result, decreases the permeability of soil.[3] Therefore, scientists and policy makers put emphasis on conservation tillage systems.

Conservation tillage

Conservation tillage (CT) is defined by the *Conservation Tillage Information Center*[4] as any tillage and planting system that covers 30 percent or more of the soil surface with crop residue after planting, to reduce soil erosion by water. Throughout much of the US, the definition of conservation tillage has been maintenance of a minimum of 30% soil cover with crop residues after planting. The CTIC has sub-divided the conservation tillage into four systems:

No-tillage (No-till, Zero-till, slot planting, eco fallow, chemical fallow, direct drilling)

The CTIC defines no-till as a system in which the soil is left undisturbed from harvest to planting except for nutrient injection. Tillage is essentially eliminated with a no-till system. The only tillage that is used is the soil disturbance in a narrow slot created by coulters or seed openers.[5] Planting or drilling is accomplished in a narrow seedbed or slot created by coulters, row cleaners, disk openers, in row chisels, or roto-tillers. Compared to other tillage systems, no-till also minimizes fuel and labor requirements. Weed control is accomplished primarily with one or two properly timed surface applications of pre-emergence or post-emergence herbicides.

Reduced tillage

Reduced tillage system is less intensive than conventional system. The number of tillage operations is minimized by either elimination of one or more tillage operations from the conventional tillage programme. Only those tillage operations are operated and performed that are absolutely necessary for crop production under a given set of soil, crop, and climatic conditions. The primary and secondary tillage operations are generally combined together. Land preparations and seeding is completed in one operation. Ploughing is normally eliminated, but the total field surface is still worked by tillage equipment. The crop residues are retained on the soil surface for as long as possible if the objective is to conserve soil and soil moisture during rainy season.

Ridge tillage

Ridge-till is a reduced disturbance planting system in which crops are planted and grown on ridges formed during the previous growing season and by shallow, in-season cultivation equipment. Tillage is generally very shallow, disturbing only the ridge tops. Planting is completed in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Ridge tillage is primarily intended for the production of agronomic row crops like corn, soybeans, cotton, etc. Level or gently sloping fields, especially those with poorly drained soils, are well suited to ridge systems. A ridge system is an excellent choice for soils that are often too wet.

Stubble or mulch-till

Mulch-till is a category that includes all conservation tillage practices other than no-till and ridge-till. Mulch tillage is described as a tillage system in which a significant portion of crop residue is left on the soil surface to reduce erosion. It is usually accomplished by substituting chisel plows, sweep cultivators, or disk harrows for the moldboard plow or disk plow in primary tillage. This change in implements is attractive because residues are not buried deep in the soil, and good aerobic decomposition is thus encouraged. Weed control is accomplished with herbicides and/or cultivation.

Conservation tillage can provide environmental benefits, including:

a. Reduced soil erosion
b. Improved moisture content in soil
c. Healthier, more nutrient-enriched soil
d. More earthworms and beneficial soil microbes
e. Reduced consumption of fuel to operate equipment
f. The return of beneficial insects, birds and other wildlife in and around fields
g. Less sediment and chemical runoff entering streams
h. Reduced potential for flooding
i. Less dust and smoke to pollute the air
j. Less carbon dioxide released into the atmosphere

Conservation tillage effects on soil physical properties

The importance of minimizing soil erosion and conserving soil resources first came to national attention in the US during the 'Dust Bowl' period in the early 1930s, when the combination of intensive tillage, drought, crop failure and wind-driven erosion of millions of acres of farmland occurred in the Great Plains region of the US.[6] Conservation agriculture emphasizes that the soil is a living body, essential to sustain quality of life on the planet. In particular, it recognizes the importance of the upper 0-20 cm of soil as the most active zone, but also the zone most vulnerable to erosion and degradation. Most environmental functions and services that are essential to support terrestrial life on the planet are concentrated in the micro, meso, and macro fauna and flora which live and interact in this zone. The success of conservation tillage depends largely on herbicides, crop residues on the soil surface, and, in the case of no-tillage, planting equipment to permit precision sowing through trash. The conservation tillage greatly affects the soil physical properties.

Soil structure and soil aggregation

Favorable soil structure and high aggregate stability are important to improving soil fertility, increasing agronomic productivity, enhancing porosity and decreasing erodibility. Soil structure or spatial heterogeneity dominates all the physical properties of soil and hence, its functioning. Improved soil structure enhances nutrient recycling, water availability and biodiversity while reducing water and wind erosion, and improving surface and ground water quality. Soil aggregation can be improved by management practices that decrease agro-ecosystem disturbances, improve soil fertility, increase organic inputs, increase plant cover, and decrease soil organic carbon decomposition rate. Better aggregation and improved pore size distribution[7] was observed by the adoption of zero tillage. Zhang et al,[8] reported the soil aggregate distribution and mean weight diameter (MWD) under different tillage systems at the depth of 0–20 cm, as shown below in Table 1.

Table 1 soil aggregate distribution and mean weight diameter (MWD) under different tillage systems at the depth of 0–20 cm

Tillage	Aggregate proportion in size class (%)				MWD
	>2 mm	2–1 mm	1–0.25 mm	<0.25 mm	
NT	56.45a	25.62b	16.57c	1.36b	2.47a
RT	46.86b	27.43ab	23.30b	2.41a	2.20b
CT	25.96c	30.46a	41.81a	1.78ab	1.63c

Letters indicate results of LSD test. NT, no tillage; RT, ridge tillage; CT, conventional tillage.

Bulk density and penetration resistance

Bulk density is a soil physical parameter used extensively to quantify soil compactness. The bulk density varies with management as well as with inherent soil qualities. Because of dependence on inherent soil properties, measurements of bulk density are of limited value as a measure of the effect of management of soil compactness when soils with different inherent characteristics are compared. Penetration resistance (kPa) of the soil can be regarded as a factor determining the quality of its structure. Penetration resistance of soil depends on its physical and mechanical properties. Keshavarzpour and Rashidi in 2008 observed that the highest soil bulk density of 1.52g cm^{-3} was obtained for the NT treatment and lowest (1.41g cm^{-3}) for the CT treatment (Table 2). The highest soil penetration resistance

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of 1250 kPa was obtained for the NT treatment and lowest (560 kPa) for the CT treatment (Table 2). The highest soil moisture content of 19.6% was obtained for the CT treatment and lowest (16.8%) for the NT treatment shown below in Table 2.

Table 2 Effect of different tillage treatments on soil physical properties (mean of 2006 and 2007)

Treatments	Soil bulk density (gcm^{-3})	Soil penetration resistance (k Pa)	Soil moisture content (%)
CT	1.41 c	560 c	19.6 a
RT	1.47 b	815 b	18.4 b
MT	1.50 ab	1105 a	17.1 c
NT	1.52 a	1250 a	16.8 c

CT=Conv.Till., RT=Reduced till. MT=Minimum Till., NT=No till.

Soil strength and stability

Strength and stability are necessary if soil is to retain its structure against imposed stresses. These imposed stresses may be natural such as raindrop impact, or may be anthropogenic such as those imposed by vehicular traffic. A complication with soil is that its strength must not be too great otherwise; plant roots and other organisms will not be able to penetrate.

Hydraulic conductivity, infiltration rate and moisture content

In general, bulk density in the upper layer of no-tillage soils was increased, resulting in a decrease in the amount of coarse pores, and lowered saturated hydraulic conductivity, when compared with the conventional and reduced tillage soils. Srivastava et al.,[9] found significantly lower hydraulic conductivity in zero tillage plots as compared to chiselling and roto-tilling, which may be due to more favorable physical conditions created by them. After rice and wheat harvest, the laboratory estimated Ksat values in the 0–15 cm soil depth under zero tillage plots were higher than that of the tilled plots.[10,11] The decrease of Ksat by tillage in the surface soil layer was probably due to destruction of soil aggregates and reduction of non-capillary pores whereas in zero tillage plots the pore continuity was probably maintained due to better aggregate stability and pore geometry.[7] Sharma et al.[12] showed that the no tillage retained the highest moisture followed by minimum tillage, raised bed and conventional tillage in inceptisols under semi arid regions of India (Figure 1). Tillage treatments influenced the water intake and infiltration rate (IR) increased in the order of NT>MT>RB>CT and in mulching treatment the order was PM>StM>SM>NM. The maximum mean value of IR (182.4 mm/day) was obtained in case of no tillage and polythene mulch combination and minimum (122.4 mm/day) was recorded in CT and no mulch combination (Figure 1 & 2).

According to Aikin & Afuakwa,[13] in the 0–10cm soil layer for the 2009 major growing season, tillage treatments showed significant influence in moisture content from the planting date through the first five weeks after planting, and after harvest. There was no significant difference in moisture content from the sixth to the eighth week after planting in the 0–10cm soil layer. In the 0–10cm soil layer for the 2010 major growing season, tillage treatments significantly affected moisture content only on the planting date, the seventh and eight week after planting, and after harvest.

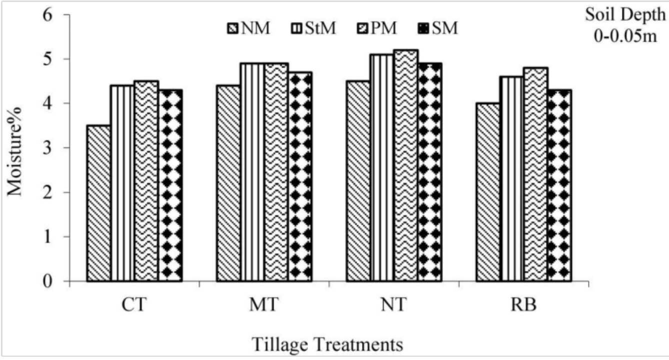

Figure 1 Effect of tillage & water management practices on soil water content at harvesting of maize (3 years average), were, CT, Conv. Till.; MT, Min. Till.; NT, No Till.; RB, Raised bed; NM, No Mulch; StM, Straw mulch; PM, Polythene Mulch; SM, Soil Mulch.

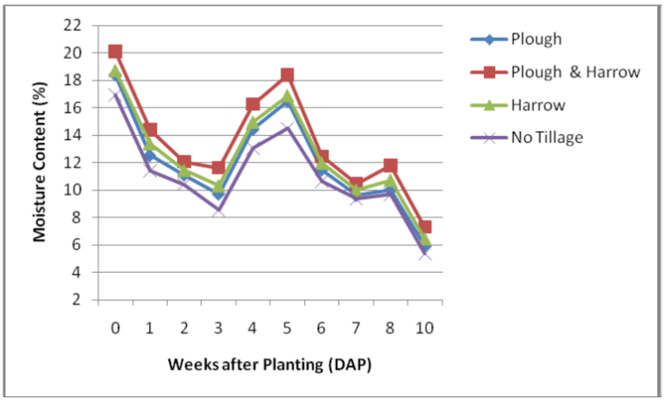

Figure 2A Effect of Tillage Practice on Moisture Content: 0–10 cm (2009).

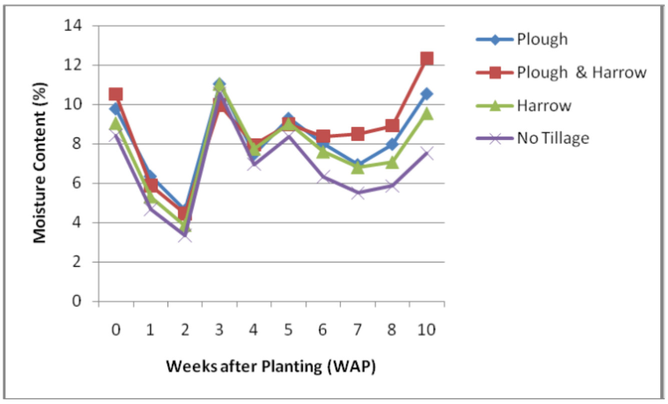

Figure 2B Effect of Tillage Practice on Moisture Content: 0–10 cm (2010).

Soil aeration and soil temperature

Aeration is important for both the agricultural and environmental functions of soil. Plant roots and soil fauna require oxygen, and aerobic microbes are important decomposers. Air permeability is a measure of how easily air convection occurs through soil in response to pressure gradients. Pressure gradients can be generated naturally by air turbulence above the soil surface, and this can lead to air flows through the tilled layers of soils especially when they contain pores larger than about 5mm.[14] One of the characteristics of the physical state of soil is its temperature. This factor is rarely analyzed, mainly

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because of its great variability in time. Radecki[15] stated that dark soils show greater warmth of the surface layer directly after agricultural treatment than when not treated.

Soil erosion

Soil erosion by wind and water occurs in all environments.[16] It takes place particularly in situations where at times the soil surface is not protected by a cover of vegetation. The greater the wind or water velocity, the greater the likelihood of particle detachment and the size of particle which can be transported. The presence of residues at the soil surface in different types of tillage systems has a tremendous effect on run-off and erosion. The residues also have an effect on soil temperature, soil reaction, nutrient distribution and availability, population and activities of soil fauna, and, therefore, on soil organic matter content Because of effectiveness of conservation tillage in controlling erosion, no-tillage makes crop production possible on sloping lands that would under clean tillage result in enormous erosion problems. No-tillage systems also ensure significant increases in water conservation.

Constraints

Factors for non-adoption of conservation tillage include climate, soil, levels of crop residue, (mixed) cropping systems to name a few. Among the disadvantages are more difficult weed control, specific machinery and cropping systems requirements, and soil specificity. For example each crop has specific soil preparation requirements (soil temperature, allopathic response,) and irrigation needs that create challenges for the universal adoption of conservation tillage. Reasons of non-adoption of conservation tillage system are summarized as follow:-

a. Lack of information on conservation tillage
b. No farms around practicing conservation tillage could serve as demonstration/example
c. Extensionists know very little or nothing about the system
d. Costs implied by changing the tillage systems
e. Lack of access to inputs and credits (for purchase of conservation tillage implements)
f. Risk avoidance (fear of failure or wrong application of new technique in the absence of guidance phase)

Conclusion

Soils are one of the world's most precious commodities. Continuing soil degradation is threatening food security and the livelihood of millions of farm households throughout the world. Soil types and their various reactions to tillage are of paramount importance in determining the superiority of one practice over the other. Socio-economic considerations, however, should always be taken into account in decision making for the adoption of one practice over another. There is a need to develop precise objective and quantitative indices of assessing the attributes e.g. economic productivity, environment regulation, and aesthetic and cultural values. A decreasing trend of runoff and soil loss is ordered when we move from tropics to temperate region. Conservation and recycling of nutrients is a major feature of any organic farming system'.[17] There is considerable evidence that CT can provide a wide range of benefits to the environment and wildlife, some of these being similar to that provided by set-aside. The reforms of the Common Agricultural Policy[18] from compulsory to voluntary set-aside may result in a decline of this valuable habitat.

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None.

Conflicts of interest

The authors declare that there is no conflict of interest.

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