

TILLAGE INFLUENCE ON CROP PRODUCTIVITY AND SOIL HEALTH

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Abstract: There is an urgent need to match food production with increasing world population through identification of sustainable land management strategies. However, the struggle to achieve food security should be carried out keeping in mind the soil where the crops are grown and the environment in which the living things survive. Soil are create physical environment suitable for seed germination, seedling emergence and root development. This process requires optimum soil water and soil temperature regimes and freedom from oxygen and mechanical stress. Tillage affect the soil physical environment though its affect on physical properties of soil. The change in bulk density which always accompanies alters the pore size distribution and porosity, volume water content and particle to particle contact. Conservation agriculture (CA), practicing agriculture in such a way so as to cause minimum damage to the environment is being advocated at a large scale world-wide. Conservation tillage, the most important aspect of conservation agriculture, is thought to take care of the soil health, plant growth and the environment.

Keywords: Tillage, Crop productivity, Soil

INTRODUCTION

The growing concern for food security through improved soil management techniques demands identification of an environmental friendly and crop yield sustainable system of tillage. Tillage is defined as the mechanical manipulation of the soil for the purpose of crop production affecting significantly the soil characteristics such as soil water conservation, soil temperature, infiltration and evapotranspiration processes. This suggests that tillage exerts impact on the soil purposely to produce crop and consequently affects the environment. As world population is increasing so the demand for food is increasing and

as such the need to open more lands for crop production arises. The yearning for yield increases to meet growing demand must be done in a way that soil degradation is minimal and the soil is prepared to serve as a sink rather than a source of atmospheric pollutants. 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 (Fig 1). The growth rate in agriculture has been the major detriment in world food production. It has been declining since past three decades.

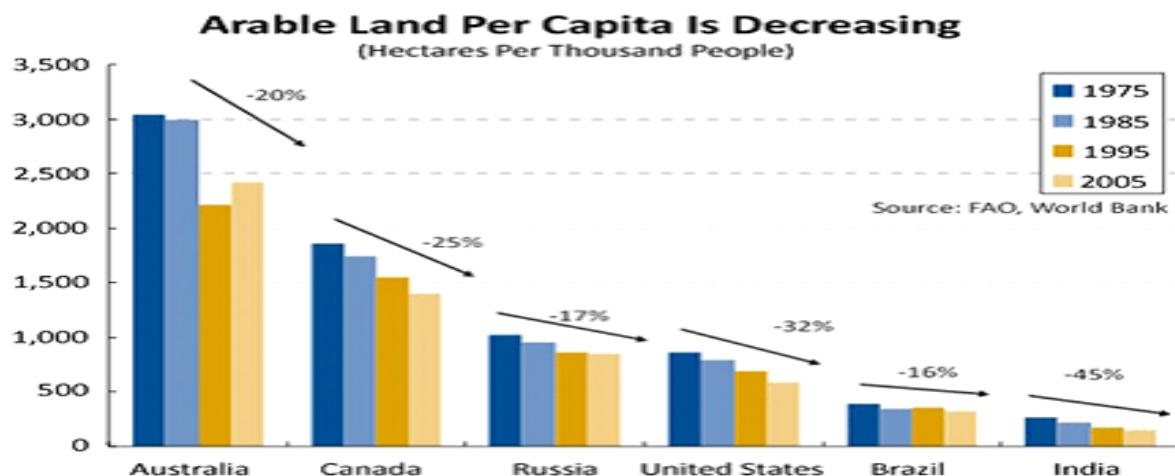


Fig. 1. Decline in arable land per capita in several countries over thirty-year period between 1975 and 2005.

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Soil tillage is among the important factors affecting soil physical properties and crop yield. Among the crop production factors, tillage contributes up to 20% (Khurshid, *et. al.*, 2006). Tillage method affects the sustainable use of soil resources through its influence on soil properties (Hammel, 1989). The proper use of tillage can improve soil related constraints, while improper tillage may cause a range of undesirable processes, e.g. destruction of soil structure, accelerated erosion, depletion of organic matter and fertility, and disruption in cycles of water, organic carbon and plant nutrient (Lal, 1993). Use of excessive and unnecessary tillage operations is often harmful to soil. Therefore, currently there is a significance interest and emphasis on the shift to the conservation and no-tillage methods for the purpose of controlling erosion process (Iqbal *et al.*, 2005). Conventional tillage practices modify soil structure by changing its physical properties such as soil bulk density, soil penetration resistance and soil moisture content. Annual disturbance and pulverizing caused by conventional tillage produce a finer and loose soil structure as compared to conservation and no-tillage method which leaves the soil intact (Rashidi and Keshavarzpour, 2007). This difference results in a change of number, shape, continuity and size distribution of the pores network, which controls the ability of soil to store and transmit air, water and agricultural chemicals. This in turn controls erosion, runoff and crop performance (Khan, *et. al.*, 2001). Soil is a key natural resource and soil quality is the integrated effect of management on most soil properties that determine crop productivity and sustainability (Anikwe and Ubochi, 2007). Tillage practices profoundly affect soil physical properties. It is essential to select a tillage practice that sustains the soil physical properties required for successful growth of agricultural crops (Jabro, *et. al.*, 2009). Seedbed preparation is crucial for crop establishment, growth and ultimately yield (Atkinson, *et. al.*, 2007). Tillage systems create an ideal seedbed condition for plant emergence, development, and unimpeded root growth (Licht and Al-Kaisi, 2005). Appropriate tillage practices are those that avoid the degradation of soil properties but maintain crop yields as well as ecosystem stability

(Greenland, 1981). The best management practices usually involve the least amount of tillage necessary to grow the desired crop. This not only involves a substantial saving in energy costs, but also ensures that a resource base, namely the soil, is maintained to produce on a sustainable basis.

Tillage effects on crop performance

Tillage impact on crop yield is related to its effects on root growth, water and nutrient use efficiencies and ultimately the agronomic yield (Lal, 1993). An increase in root length density has been found only in the upper soil layers of non tillage (Martinez, *et. al.*, 2008) and reduced tillage systems compared to the conservation system because soil compaction of deeper soil layers under non tillage may impede proper development of roots. However, Malhi and Lemke (2007) reported a 22% increase in root mass under non tillage compared with conservation tillage. This could be attributed to the cracks, worm channels and higher number of biopores which may facilitate root growth under non tillage. According to Busari and Salako (2013), maize yield under a minimum tillage system is likely to be more sustainable compared with conventional tillage. They added that best crop yield under non tillage than other tillage methods could be linked with poor root development that is usually associated with low yield under zero tillage and rapid structural deterioration caused by slaking and dispersion under conservation tillage (Guzha, 2004) which were possibly not the case under minimum tillage.

The effect of tillage systems on crop yield is not uniform with all crop species, in the same manner as various soils may react differently to the same tillage practice. Francis & Knight, 1993, compared the traditional tillage, traditional tillage (the soil was ploughed by mouldboard, to a 30 cm depth, after burning the straw of the preceding crop) and conservation tillage, conservation tillage, (the residues of the previous crop were left on the soil surface, as mulch, and a minimum vertical tillage (chiseling, 25 cm depth) and disc harrowing (5 cm depth) were carried out. Results revealed that crops yield was higher in conservation tillage, (Table 1).

Table 1. Effect of tillage on crop yield

Crop	Treatment	Thousand kernel weight (g)	Yield (kg ha ⁻¹)
Sunflower	CT	54.5	>2,000
	TT	56.0	>2,000
Wheat	CT	47.3	3,094
	TT	46.6	2,517

Results presented by Nicou and Charreau (1985) showed the effect of tillage on yields of various crops in the West African semi-arid tropics (Table 2). Cotton showed the smallest yield increase with tillage within the range of crops tested. Tillage effects in semi-arid zones are closely linked to moisture conservation and hence the management of

crop residues. Several authors (Unger, *et. al.* 1991; Thomas, *et. al.* 1990, Sharma, *et. al.* 2009) emphasize the link between crop residue management and tillage and recognize them as the two practices with major impact on soil conservation in the semi-arid zones.

Table 2. Effect of tillage on crop yields in the West African semi-arid tropics

Crop	Number of annual results	Yield (kg ha ⁻¹)		Yield increase (%)
		control	with tillage	
Millet	38	1558	1894	22
Sorghum	86	1691	2118	25
Maize	31	1893	2791	50
Rice	20	1164	2367	103
Cotton	28	1322	1550	17
Groundnut	46	1259	1556	24

Soil physical properties

Effects of conservation tillage on soil properties vary, and these variations depend on the particular system chosen. No-till (NT) systems, which maintain high surface soil coverage, have resulted in significant change in soil properties, especially in the upper few centimeters (Anikwe & Ubochi, 2007). Soil physical properties are generally more favorable with no-till than tillage-based systems. Many researchers have found that NT significantly improved saturated and unsaturated hydraulic conductivity owing to either continuity of pores or flow of water through very few large pores (Benjamin, 1993).

Most studies on cereal production comparing conventional and conservation tillage have given inconsistent results, apparently depending on soil type, crop rotation, and local climatic conditions (Martin- Rueda *et al.* 2007). Studies carried out by Malhi (2007) indicate that the yield of spring barley decreased by 8% when plowing tillage was replaced by reduced tillage, and it decreased by 12% when no tillage was applied. Higher water holding capacity or moisture content has been found in the topsoil (0–10 cm) under NT than after ploughing. Therefore, to

improve soil water storage and increase water use efficiency (WUE) most researchers have proposed replacement of traditional tillage with conservation tillage (Fabrizzi, *et.al.*,2005).

Soil penetration resistance is a measure of the soil strength and an indicator of how easily roots can penetrate into the soil and thus a measure of plant growth and crop yield. Soil penetration resistance before tillage operation under all tillage implements. Penetrometer resistance measurements of soil can be used to assess the need for tillage operations, which help maintain effective plant rooting and facilitate good water and nutrient uptake.Irena, *et. al.*, 2012 observed the soil tillage systems significantly modified soil bulk density in the spring vegetation period of spring barley only in the upper soil layer ($P < 0.01$) (Table 3). At the 0-5 cm depth, RT caused an increase in the soil bulk density value in the surface soil layer of 0.15 Mg m⁻³, and NT caused an increase of 0.30 Mg m⁻³ as compared with CT. Differences in bulk density between tillage systems were not significant at the 10-20 cm depth; however, bulk density in CT was slightly lower than in RT and NT.

Table 3. Volumetric water content and soil bulk density as affected by tillage system (mean of 2004-2006). (Irena *et. al.*, 2012)

Tillage systems ^a	Volumetric water content (%)		Bulk density (Mg m ⁻³)	
			Soil layer (cm)	
	0-5	10-20	0-5	10-20
CT	12.2 c	16.4 b	1.39 c	1.59
RT	15.3 b	18.0 a	1.54 b	1.62
NT	17.6 a	18.9 a	1.69 a	1.64

LSD values			
Tillage systems	1.61**	1.32**	0.075**NS

The means in a column with the same letter are not significantly different. NS: not significant; ** $P < 0.01$.

^aTillage systems: CT, conventional tillage; RT, reduced tillage; NT, no-tillage.

Conservation in soil tilled with chisel plow and mouldboard plow whereas the rotary harrow further increased the soil moisture contents with all tillage implements. Similarly, Makki and Mohamed (2008) also observed the highest moisture conservation in soil tilled with chisel plow compared to other tillage implements. Cogle, *et. al.* (1997) also reported that

deep tillage increases the soil porosity and manipulate surface roughness to improve water intake. The deep tillage decreased soil bulk density and penetration resistance up to the tilled depth 40 cm and encouraged more root growth in the deeper soil layers, which in turn, increased water holding capacity (Meherban and Chaudhury, 1998).

Soil chemical properties

Soil chemical properties that are usually affected by tillage systems are pH, CEC, exchangeable cations and soil total nitrogen. According to Lal, (1997b) soil chemical properties of the surface layer are generally more favorable under the no till method than under the tilled soil. Annual no-tillage, implying yearly practice of no-till system over a long period of time, is beneficial to maintenance and enhancement of the structure and chemical properties of the soil, most especially the SOC content. In study observed that with annual no-tillage, plant residues left on the soil surface increase the organic matter in the topsoil. Similarly, Lal, (1997b) reported a significantly higher SOC in soil with no-tillage compared to un-tilled soil.

A reduced total N loss was also observed under no-tillage compared to conservation tillage by Dalal, (1992). Higher mineralization and/or leaching rate could be implicated for reduction in organic C and total N under tilled plot due to soil structure deterioration following tillage. Tillage technique is often shown to have no effect on soil pH (Rasmussen, 1999), though soil pH has been reported to be lower in no-till systems compared to conservation tillage. The lower pH in zero tillage was attributed to accumulation of organic matter in the upper few centimeters under zero tillage soil causing increases in the concentration of electrolytes and reduction in pH (Rahman, *et. al.*, 2008). Conversely,

Cookson, *et.al.*,(2008) found that surface soil pH decreased with increasing tillage disturbance and reported a significantly higher soil pH in no-tillage plots compared to those in tilled plots. Therefore, tillage may not directly affect soil pH but its effects on pH will depend on the prevailing climatic condition, soil type and management factors. Rahman, *et. al.* (2008) reported that exchangeable Ca, Mg, and K, were significantly higher in the surface soil under no-tillage compared to the ploughed soil. Lowest values of soil OM, N, P, K, Ca and Mg were recorded in conventional till plots and it could be due to the inversion of top soil during ploughing which shifts less fertile subsoil to the surface in addition to possible leaching.

Busari and Salako (2013) observed that zero tillage soil had a significantly higher pH at the end of the first year after tillage but the pH became significantly lower compared with the conservation tillage soil at the end of the second year after tillage. However, the soil organic C (SOC) and the effective cation exchange capacity (ECEC) were significantly higher at the end of the two years of study under zero tillage than under conservation tillage (Table 4). The study however, revealed that minimum tillage (MT) resulted in significantly higher pH and SOC than conservation tillage at the end of each of the two years of the study suggesting that less soil disturbance is beneficial to soil chemical quality improvement.

Table 4. Effect of tillage on soil chemical properties.

Source: Busari and Salako (2013)

Tillage	2008					2009				
	pH (H ₂ O)	OC (g kg ⁻¹)	TN (g kg ⁻¹)	Avail. P (mg kg ⁻¹)	ECEC (cmol kg ⁻¹)	pH (H ₂ O)	OC (g kg ⁻¹)	TN (g kg ⁻¹)	Avail. P (mg kg ⁻¹)	ECEC (cmol kg ⁻¹)
CT	6.0	16.50	1.38	26.64	6.31	6.69	2.79	0.32	65.59	8.05
MT	6.2	19.80	1.52	24.33	6.24	6.79	4.59	0.55	40.47	8.51
ZT	6.1	21.20	1.58	33.28	7.36	6.64	5.00	0.53	61.13	9.39
LSD (Pr0.05)	0.05	2.20	ns	7.13	0.49	0.04	0.44	0.08	13.25	0.79
OC%organic c carbon; TN%total; MT%minimum tillage; CT%conventional tillage; LSD=least significant difference; ns%not significant.	nitrogen Avail. P %available phosphorus,					ECEC%effective cation exchange capacity;				

Soil biological properties

The soil biological property most affected by tillage is SOC content (Doran, 1980). The soil organic matter content influences to a large extent the activities of soil organism which in turn influence the SOC dynamics. Earthworms which are a major component of the soil macrofauna are important in soil fertility dynamics as their burrowing activities aid in improvement of soil aeration and water infiltration. The fact that the population of earthworms are affected by tillage practices has been documented in a ploughless tillage review by Rasmussen (1999). A six year study by Andersen (1987) revealed a significantly higher earthworm

population under no-till soil than under ploughed soil. Kemper, *et. al.* (1987) reported that less intense tillage increased the activities of surface-feeding earthworms. Due to disruption of fungi mycelia by tillage technique, Cookson, *et. al.* (2008) observed a decreased fungal biomass and increased bacterial biomass with increasing tillage disturbance. They also reported alteration in the composition and substrate utilization of the microbial community with distinct substrate utilization in no-till soil.

Strategies for mitigating challenges

Conservation agriculture (CA) is a concept for resource-saving agricultural crop production that

strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. Interventions such as mechanical soil tillage are reduced to an absolute minimum and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with or disrupt the biological processes. One of the soil conservation techniques developed in USA is known as 'conservation tillage'(CT), this involves soil management practices that minimize the disruption of the soil's structure, composition and natural biodiversity, thereby minimizing erosion and degradation, but also water contamination (Anonymous, 2001).

Principles of conservation agriculture

Conservation agriculture systems utilize soils for the production of crops with the aim of reducing excessive mixing of the soil and maintaining crop residues on the soil surface in order to minimize damage to the environment. This is done with objective to:

- Provide and maintain an optimum environment of the root-zone to maximum possible depth.
- Avoid physical or chemical damage to roots that disrupts their effective functioning.
- Ensure that water enters the soil so that a plants never or for the shortest time possible, suffer water stress that will limit the expression of their potential growth; and so that residual water passes down to groundwater and stream flow, not over the surface as runoff.
- Favour beneficial biological activity in the soil

Conservation tillage is now commonplace in areas where rainfall causes soil erosion or where preservation of soil moisture because of low rainfall is the objective. World-wide, Conservation tillage is practiced on 45 million ha, most of which is in North and South America (FAO, 2001) but is increasingly being used in other semi-arid and tropical regions of the world (Lal, 2000b). In USA, during the 1980s, it was recognized that substantial environmental benefits could be generated through soil conservation and to take advantage of this policy goals were changed. These were successful in reducing soil erosion; however, the social costs of erosion are still substantial, estimated at \$37.6 billion annually (Lal, 2001). World-wide erosion caused soil degradation was estimated to reduce food productivity by 18 million Mg at the 1996 level of production (Lal, 2000b). Because of the increasing population and rising standards of living, it is essential to develop those agricultural practices that maximize agricultural production while also enhancing ecosystem services. Eco-efficiency is related to both "ecology" and "economy," and denotes both efficient and sustainable use of resources in farm production and land management (Willcocks, 1988). Experience

has shown that conservation agriculture systems achieve yield levels as high as comparable conventional agricultural systems but with less fluctuations due, for example, to natural disasters such as drought, storms, floods and landslides. Conservation agriculture therefore contributes to food security and reduces risks for the communities (health, conditions of living, water supply), and also reduces costs for the State (less road and waterway maintenance).

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. Conservation agriculture permits management of soils for agricultural production without excessively disturbing the soil, while protecting it from the processes that contribute to degradation e.g. erosion, compaction, aggregate breakdown, loss in organic matter, leaching of nutrients etc. Conservation agriculture is a way to achieve goals of enhanced productivity and profitability while protecting natural resources and environment. Therefore, to achieve sustainable food production with minimal impact on the soil and the atmosphere, conservation tillage practices become more important now than ever. Research reports indicate that conservation tillage, particularly minimum tillage, is better than continuous tillage in terms of soil chemical improvement. All available reports are in agreement that soils under conservation tillage are more favored than continued tillage in terms of physical and chemical properties, crop performance, soil fauna activities and biological properties improvement.

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