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Tillage Effects on Soil Health and Crop Productivity: A Review

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1. Introduction

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.

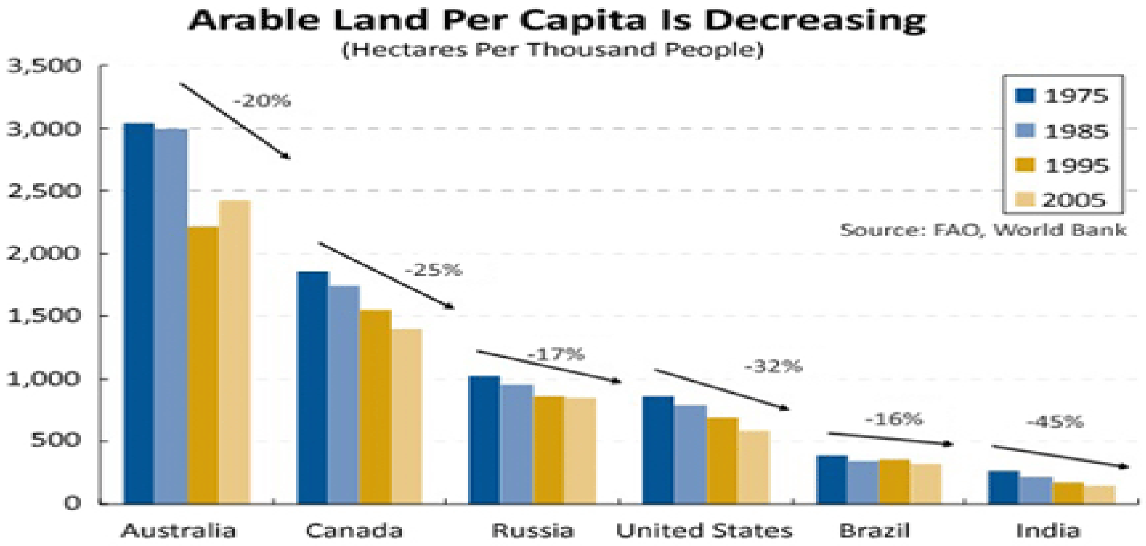


Fig. 1. Decline in arable land per capita in several countries over thirty-year period between 1975 and 2005.

The cultivation of agricultural soils has until recently predominantly been achieved by inverting the soil using tools such as the plough. Soil tillage is one of the basic and important components of agricultural production technology. Various forms of tillage are practised throughout the world, ranging from the use of simple stick or jab to the sophisticated para-plough. The practices developed, with whatever equipment used, can be broadly classified into no tillage, minimum tillage, conservation tillage and conventional tillage. Energy plays a key role in the various tillage systems. Soil tillage is defined as physical, chemical or biological soil manipulation to optimize conditions for germination, seedling establishment and crop growth (Lal, 1979a, 1983). Ahn and Hintze (1990), however, defined it as any physical loosening of the soil carried out in a range of cultivation operations, either by hand or mechanized. For any given location, the choice of a tillage practice will depend on one or more of the following factors (Lal 1980; Unger 1984): i) Soil factors includes Relief, Erodibility, Erosivity, Rooting depth, Texture and structure, Organic-matter content & Mineralogy ; ii) Climatic factors includes Rainfall amount and distribution, Water balance, Length of growing season, Temperature (ambient and soil), Length of rainless period; iii) Crop factors includes Growing duration, Rooting characteristics, Water requirements, Seed ; Socio-economic factors includes Farm size, Availability of a power source, Family structure and composition, Labour situation. Tillage is a labour-intensive activity in low-resource agriculture practised by small land-holders, and a capital and energy-intensive activity in large-scale mechanized farming (Lal 1991). Continual soil inversion can in some situations lead to a degradation of soil structure leading to a compacted soil composed of fine particles with low levels of soil organic matter (SOM). Such soils are more prone to soil loss through water and wind erosion eventually resulting in desertification, as experienced in USA in the 1930s (Biswas, 1984). This process can directly and indirectly cause a wide range of environmental problems. 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 (Wang et al. 2007). Therefore, scientists and policy makers put emphasis on conservation tillage systems. Compared to conventional tillage, there are several benefits from conservation tillage such as economic benefits to labor, cost and time saved, erosion protection, soil and water conservation, and increases of soil fertility (Uri et al. 1998, Wang and Gao 2004)

Conservation tillage (reduced tillage) can lead to important improvements in the water storage in the soil profile (Pelegrín, 1990; Moreno *et al.*, 1997, 2001). Tillage operations generally loosens the soil, decreases soil bulk density and penetration resistance by increasing soil macroporosity. Under these conditions, improvements were also obtained in crop development and yield, especially in very dry years (Pelegrín et al., 1990; Murillo et al., 1998, 2001). Mahboubi et al (1993) in a 28 years long term experiment found that no-tillage resulted in higher saturated hydraulic conductivity compared with conventional tillage on a silt loam soil in Ohio. Whereas, Chang and Landwell (1989) did not observe any changes in saturated hydraulic conductivity after 20 years of tillage in a clay loam soil in Alberta. Saturated hydraulic conductivity of silt clay loam soil was higher when subject to 10 years of tillage than no-tillage in Indiana (Heard et al., 1988). They attributed the higher hydraulic conductivity of tilled soil to greater number of voids and abundance soil macropores caused by the tillage implementation. Studies comparing no-tillage with conventional tillage systems have given different results for soil bulk density. (Osunbitan et al., 2005) found that soil bulk density was greater in no-till in the 5 to 10 cm soil depth however Logsdon et al., (1999) reported no differences in bulk density between tillage systems. The ambiguous nature of these research findings call for additional studies of the effect of long-term tillage on soil properties under various tillage practices in order to optimize productivity and maintain sustainability of soils.

Since tillage strongly influences the soil health, it is important to apply that type of technology that will make it feasible to sustain soil properties at a level suitable for normal growth of agriculture crop. Appropriate tillage practices are those that avoid the degradation of soil properties but maintain crop yields as well as ecosystem stability (Lal 1981b, c, 1984b, 1985a; 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.

2. Tillage effects on crop yield

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. Murillo et al., (2004) compared the traditional tillage, TT (the soil was ploughed by mouldboard, to a 30 cm depth, after burning the straw of the preceding crop) and conservation tillage, CT (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 CT (Table 1)

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

Table 1. Effect of tillage on crop yield

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; Larson 1979; Brown et al. 1989; 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. Residue retention in a cropping system in Burkina Faso significantly increased the yield of cowpeas as shown in Table 3 (IITA/SAFGRAD 1985).

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

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

Preceding crop	**Residue management system**^{1}	**Date of flowering**^{2}	**Date of maturity**^{2}	**Yield (kg ha^{-1})**
Maize	Residues removed	48.7	71.2	436
Crotalaria	Residues retained	46.6	69.2	918
Maize	Residues retained	45.7	68.5	921
LSD (0.05)		1.6	1.0	175

^{1}No tillage in all treatments ^{2} Number of days after planting

Table 3. Effect of cropping sequence and residue management on cowpea reproductive physiology and grain yield in the Sudan Savannah of Burkina Faso

It is evident from the extensively published data on tillage that crop yields under conventional tillage are superior to those under conservation tillage. However, several other studies show contradictory results. In both cases the economics of the tillage input are not considered, namely energy and labour costs as well as capital investment in equipment. Underwood et al. 1984; Frengley 1983 and Stonehouse 1991 observed conservation tillage superior and a more cost effective farming practice than conventional tillage on some soils and under certain climatic conditions. Although conservation tillage is being widely adopted, there is strong evidence that soils prone to surface crusting and sealing would benefit from conventional tillage once every 2 or 3 years. Rao et al. (1986) found that conventional tillage is superior to no tillage, reduced tillage or mulching with a number of crops - sun hemp (*Crotalaria juncea*), barley (*Hordeum vulgare*), mustard (*Brassica juncea*) and chickpea (*Cicer arietinum*) grown in the dry season. Nicou (1977) and Charreau (1972; 1977) showed that soil inversion and deep ploughing increases plant-available water and crop yields as compare to the no tillage in West African semi-arid regions. Similar data showing greater responses to tillage than no tillage or greatly reduced tillage were reported by Karaca et al. (1988), Prihar and Jalota (1988) and Willcocks (1988) on a variety of soils.

Mulch management	**Tillage Treatments**									
	Grain Yield of Maize (kgha^{-1})					**Grain Yield of Wheat (kgha^{-1})**				
	CT	**MT**	**NT**	**RB**	**Mean**	**CT**	**MT**	**NT**	**RB**	**Mean**
No Mulch (NM)	1370	1365	1246	1255	1308	1080	1063	930	1025	1024
Straw Mulch (StM)	2020	1990	1776	1896	1920	1410	1430	1210	1335	1346
Polythene Mulch (PM)	2183	2137	1930	2007	2065	1505	1510	1360	1450	1456
Soil Mulch (SM)	1890	1860	1730	1851	1832	1320	1360	1110	1265	1263
Mean	1865	1837	1670	1752		1328.7	1340	1152	1268	
CD (P=0.05)	M=150 S=180 M at S=160 S at M=253					M=145 S=193 M at S=301 S at M= NS				

Where Conventional tillage (CT), Minimum Tillage (MT), No Tillage (NT), Raised Bed (RB); M= Tillage Treatments, S= mulching Treatments, M at S= Interaction of tillage on same level of Mulch, S at M= Interaction of Mulch on same level of tillage (Sharma et al. 2011)

Table 4. Effect of tillage and mulching on grain yield of Maize and Wheat in semi arid tropics, India (Average of three years)

Sharma et al. (2011) reported that the greatest maize yield of 1865 kgha^{-1} was achieved with conventional tillage (CT) system while not significantly lower yield was achieved with minimum tillage (MT) system (1837 kgha^{-1}). However, higher wheat yield was recorded in MT as compare to the CT in maize –wheat rotation (Table 4).

3. Tillage effects on soil properties

3.1 Tillage effects on soil degradation

Soil erosion has conventionally been perceived as one of the main causes of land degradation and the main reason for declining yields in tropical regions. Intensive or inappropriate tillage practices have been a major contributor to land degradation. The last four decades has seen a major increase in intensive agriculture in the bid to feed the world population more efficiently than ever before. In many countries, particularly the more developed countries, this intensification of agriculture has led to the use of more and heavier machinery, deforestation and landuse changes in favour of cultivation. This has led to several problems including loss of organic matter, soil compaction and damage to soil physical properties. Soil tillage breaks down aggregates, decomposes soil organic matter, pulverizes the soil, breaks pore continuity and forms hard pans which restrict water and air movement and root growth. On the soil surface, the powdered soil is more prone to sealing, crusting and erosion. Improving soil physical fertility involves reducing soil tillage to a minimum and increasing soil organic matter (Fig. 2).

Fig. 2. Physical degradation of a soil as a result of intensive tillage

Tillage-induced soil erosion in developing countries can entail soil losses exceeding 150 t/ha^{-1}. annually and soil erosion, accelerated by wind and water, is responsible for 40 percent of land degradation world-wide. Several more recent studies have shown that no-tillage systems with crop residue mulch can increase nutrient use efficiency (Lal 1979a, b, c; Hulugalle et al. 1985). The no-till system seems to have a broad application in humid and sub-humid regions, for which 4-6 tons ha^{-1} of residue mulch appears optimal (Lal 1975; Aina et al. 1991). The beneficial effect of conservation tillage systems on soil loss and runoff have been demonstrated in studies conducted by ICRISAT (1988) and Mensah bonus and Obeng (1979) (Table 5 & 6).

Treatment	Sorghum grain yield[1]	Runoff[2] (mm)	Soil loss[2] (t ha^{-1})
10 cm deep traditional ploughing	2.52	128	1.66
15 cm non inverted primary tillage	2.83	102	1.62
15 cm deep mouldboard ploughing	2.76	106	1.70
25 cm deep mouldboard ploughing	3.22	85	1.41
S.E	+0.07	+4.9	+0.279

[1]Average values of four years (1983, 1984, 1986 and 1987) [2] Average values of 1986 and 1987

Table 5. Effect of different tillage treatments on sorghum grain yield, runoff and soil loss under Luvisols (ICRISAT Centre 1983-1987)

Treatment	Soil loss (t ha^{-1}yr^{-1})		Runoff (%)	
	Kwadaso	Ejura	Kwadaso	Ejura
Bare fallow	313.0	18.3	49.8	36.4
No-tillage	1.96	9.2	3.4	0.52
Mulching	0.42	1.9	1.4	0.33
Ridging (across slope)	2.72	4.5	1.9	1.30
Minimum tillage	4.90	3.8	1.7	1.10
Traditional mixed cropping	33.6	2.5	13.2	5.10

Table 6. Effects of tillage systems on soil loss and runoff in Ghana (1976)

3.2 Tillage effects on water content

Tillage effects differ from one agro-ecological zone to the other. In semi-arid regions moisture conservation is one of the key factors to consider. Nicou and Chopart (1979) showed that tillage and residue management increased soil profile water content. The soil was mechanically tilled to a depth of 20-30 cm (Table 7).

Tillage system	Profile water content (mm)
No till, residues burnt	49.4
Ploughing, residues incorporated	95.8
Ploughing, residues incorporated followed by addition of external mulch	103.7

Table 7.Effect of tillage system on profile water content to a depth of 1 m at 2 weeks after planting

Sharma et al. (2011) 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 (Fig 3). 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 (Fig 4).

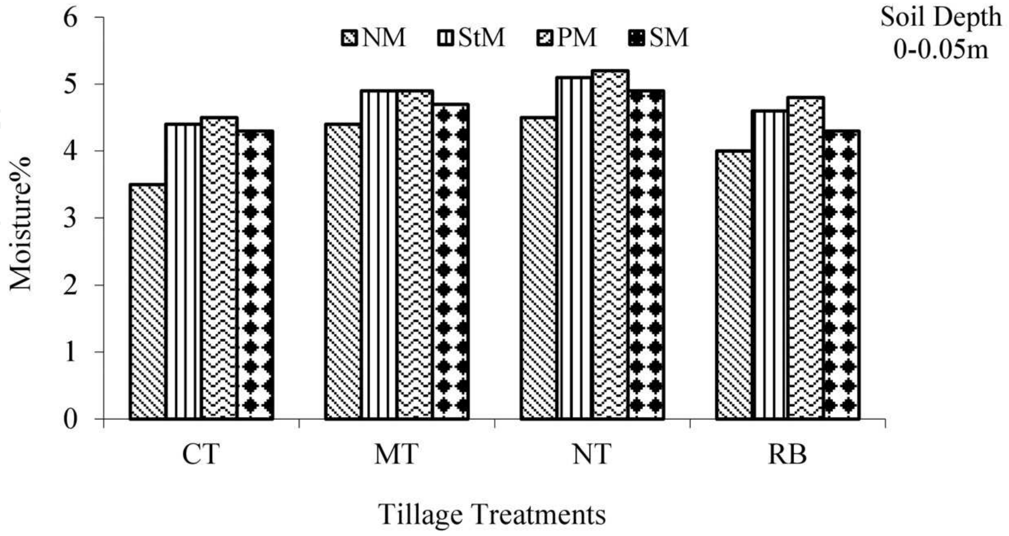
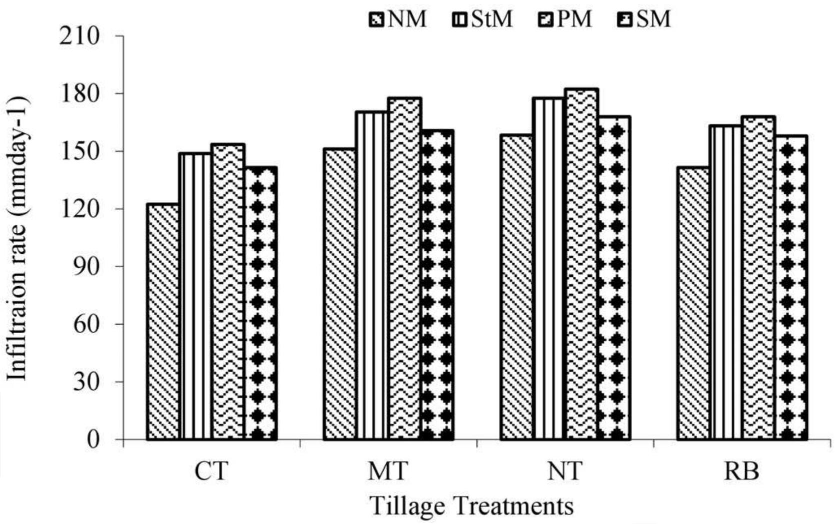


Fig. 3. Effect of tillage & water management practices on soil water content at harvesting of maize (3 years average), were, CT=Conv. Till., MT=Min. Till., NT=No Till., RB=Raised bed, NM=No Mulch, StM=Straw mulch, PM=Polythene Mulch and SM=Soil Mulch

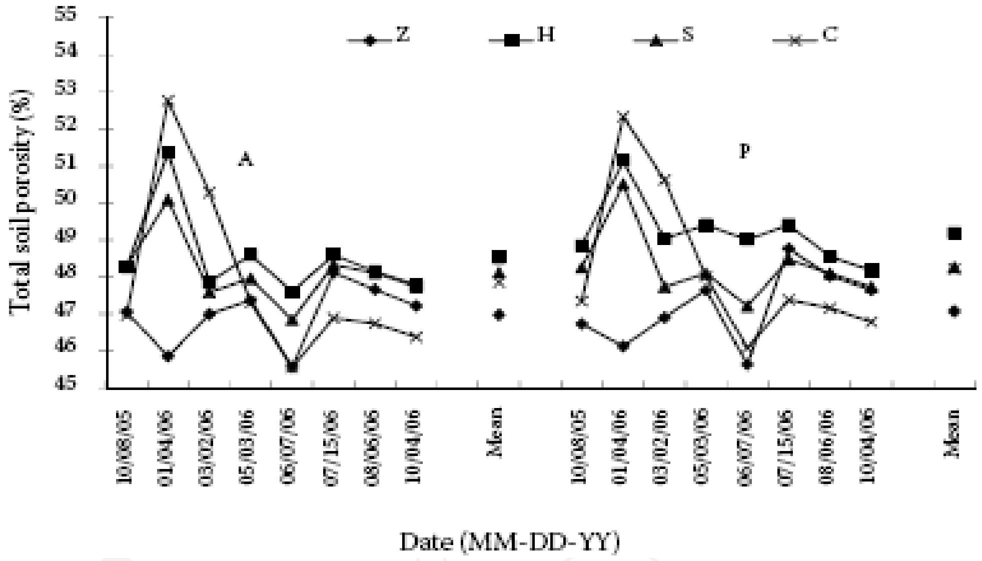


CD (P=0.05), M=9.6, S=5.52, M at S=14.4, Sat=NS, where, M=Till. Treats.; S= Mulch Treats

Fig. 4. Several researchers also show the importance of tillage on soil moisture (Lal 1977; Klute 1982; Norwood et al. 1990). Tillage enhances soil water storage by increasing soil surface roughness and controlling weeds during a fallow. This stored water may improve subsequent crop production by supplementing growing season precipitation (Unger and Baumhardt, 1999). Several studies shown that deep tillage has immense potential for water storage and better crop production. Schillinger (2001) and Lampurlanes et al. (2002) observed no difference in water storage efficiency of reduced tillage in comparison with other tillage systems.

3.3 Tillage effects on porosity

Soil porosity characteristics are closely related to soil physical behavior, root penetration and water movement (Pagliai and Vignozzi 2002, Sasal et al. 2006) and differ among tillage systems (Benjamin 1993). Lal et al. (1980) revealed that straw returning could increase the total porosity of soil while minimal and no tillage would decrease the soil porosity for aeration, but increase the capillary porosity; as a result, it enhances the water capacity of soil along with poor aeration of soil (Wang et al.1994, Glab and Kulig 2008). However, Borresen (1999) found that the effects of tillage and straw treatments on the total porosity and porosity size distribution were not significant. Allen et al. (1997) indicated that minimal tillage could increase the quantity of big porosity. Tangyuan, et al. (2009) showed that the soil total porosity of 0–10 soil layer was mostly affected; conventional tillage can increase the capillary porosity of soil and the porosities were C > H > S (Figure 5) but the non-capillary porosity of (S) was the highest. Returning of straw can increase the porosity of soil.



Where, Conventional tillage (C), Zero-tillage (Z), Harrow-tillage (H) and Subsoil-tillage (S), Straw absent (A) or Straw present (P)

Fig. 5. Tillage and residue management effect on soil porosity

The increase in plant available water capacity of the soil under different tillage treatments was found to decrease with an increase in the level of compaction. Because compaction results in the breaking down of larger soil particle aggregates to smaller ones, it is difficult for water to drain out of the soils because of the greater force of adhesion between the micropores and soil water. For the same tillage treatment, the effect of increasing the axle load upon a soil is to decrease the total porosity and to increase the percentage of smaller pores as some of the originally larger pores have been squeezed into smaller ones by compaction (Hamdeh, 2004) (Fig 6).

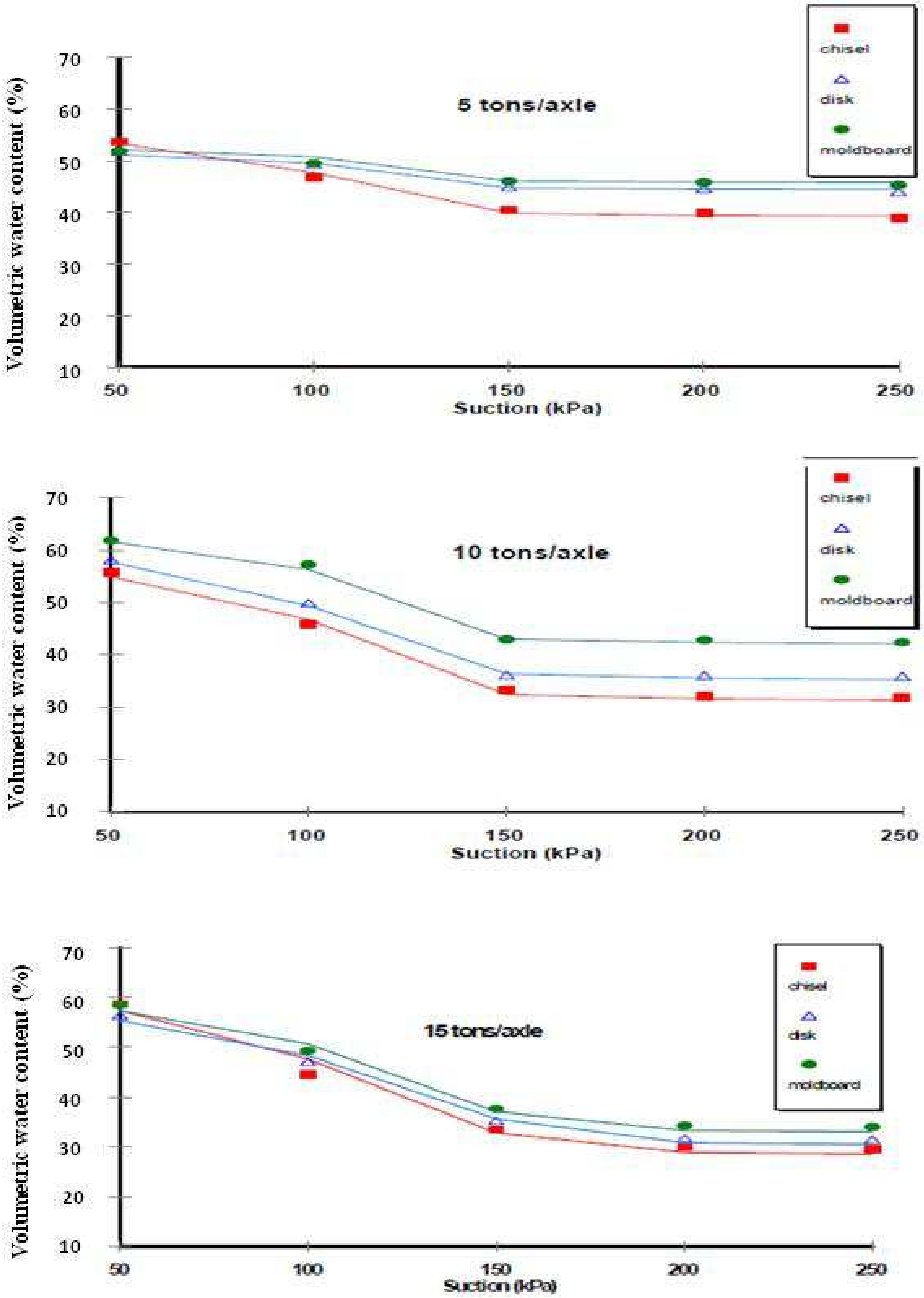


Fig. 6. Water retention curves for different axle load levels and different tillage system

3.4 Tillage effects on bulk density

The two of the most commonly measured soil physical properties affecting hydraulic conductivity are the soil bulk density and effective porosity as these two properties are also fundamental to soil compaction and related agricultural management issues (Strudley et al. 2008). The studies comparing no-tillage with conventional tillage systems have given different results for soil bulk density. Several studies showed that soil bulk density was greater in no-till in the 5 to 10 cm soil depth (Osunbitan et al. 2005). No differences in bulk density were found between tillage systems (Logsdon et al. 1999). However Tripathi et al. (2005) found increase in bulk density with conventional tillage in a silty loam soil. Moreover, there are few studies that have examined changes in soil physical properties in response to long term tillage and frequency management (> 20 yr) in the northern Great Plains. Rashidi and Keshavarzpour (2008) observed that the highest soil bulk density of 1.52 g cm^{-3} was obtained for the NT treatment and lowest (1.41 g cm^{-3}) for the CT treatment (Table 8). The highest soil penetration resistance of 1250 kPa was obtained for the NT treatment and lowest (560 kPa) for the CT treatment (Table 8). The highest soil moisture content of 19.6% was obtained for the CT treatment and lowest (16.8%) for the NT treatment .

Treatments	**Soil bulk density** (gcm^{-3})	**Soil penetration resistance** (kPa)	**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.

Table 8. Effect of different tillage treatments on soil physical properties (mean of 2006 and 2007). Means followed by the same letter in the same column are not significantly different at the 1% level

Hamdeh, 2004 reported that, the vehicle significantly increased soil dry density to a depth of 40 cm for all treatments at 10 cm depth. The MB treatment caused the maximum percentage increase of dry bulk density at all depths. This indicated the significant effects of axle load on soil physical properties. The percentage difference for each treatment was less at the 10-20 cm depth than at the 0-10 cm depth. These results reflect a more compact soil layer at the 0-10 cm depth than at the 10-20 cm depth. The averages of percentage increase of dry density at the 0-20 cm depth show that the MB treatment had the highest effect while the CS treatment had the lowest effect. These results suggested that tyre traffic followed by tillage might have a significant affect on the resulting soil physical properties. There is no significant difference ($P < 0.1$) between the ML and the CB at the 20-30 cm depth. At 20-40 cm depth MB treatment had the greatest percentage increase of dry bulk density while the CS treatment had the lowest percentage increase of dry bulk density. Results demonstrate that the axle load is crucial factor for the depth of subsoil compaction. An increase in axle wheel loads resulted in greater soil compaction due to increased in both shear and vertical soil stresses.

Treatment	Water use (cm)	Grain yield (kg ha^{-1})	Water use efficiency (kg $ha^{-1}cm^{-1}$)	Plant population at harvest (per plot)[1]
Conventional tillage	32.15	3106a	96.61a	180a
Plough	29.64	2923a	98.62a	179a
Zero tillage	30.44	2639b	86.70b	160b
Manual	29.19	2692b	92.22ab	188a
Conventional tillage	48.19	5240a	108.74a	203a
Plough	47.64	5067a	106.36a	198ab
Zero tilage	49.20	4612b	96.08b	194ab
Manual	48.00	4612b	96.08b	194ab
Conventional tillage	49.60	5533a	111.55a	207a
Plough	50.01	4998b	99.94b	205a
Zero tillage	50.14	5949c	118.65c	203a
Manual	49.01	4303d	87.69d	199a
Conventional tillage	49.54	5259a	106.16a	200a
Plough	48.92	5174a	105.16a	206a
Zero tillage	49.69	5887b	118.47b	198a
Manual	49.01	4103c	83.72c	204a
Conventional tillage	49.62	5384a	108.50	202a
Plough	49.94	5238a	104.80a	199a
Zero tillage	49.21	5678b	115.38b	205b
Manual	48.64	3713c	76.34c	197a

[1] Means followed by the same letter in the same column are not significantly different at the 5% level.

Table 9. Effect of tillage practices on water use, maize yield and water-use efficiency (early season) (Osuji 1984)

3.5 Tillage effects on water use efficiency

Nigeria, Osuji (1984) observed that water-use efficiency and maize grain yields were significantly higher under zero tillage than under other tillage treatments (Table 9). Lal (1985c) showed that soil physical properties and chemical fertility were substantially worse in ploughed watersheds after six years of continuous mechanized farming and twelve crops of maize, while the decline in the soil properties was decidedly less in the no-tillage watershed. The lower maize yields of the ploughed watershed are related to erosion, compaction, fall in organic matter content and fall in pH. After 10 years of continuous comparative no-tillage and conventional tillage trails in Southwest Nigeria, Opara-Nadi and Lal (1986) observed that total porosity, moisture retention, saturated and unsaturated hydraulic conductivity, and the maximum water-storage capacity increased under no-tillage with mulch.

3.6 Tillage effect on environment

CT Tillage may affect the production of nitrous oxide through its effect on soil structural quality and water content (Ball et al., 1999). CT can prevent nutrient loss (Jordan et al. 2000) (Table 10).

Measurements	**Plough**	**Non- inversion tillage**	**Benefit compared to ploughing**
Runoff (L ha^{-1})	213328	110275	48 % reduction
Sediment loss (kg ha^{-1})	2045	649	68 % reduction
Total P loss (kg P ha^{-1})	2.2	0.4	81 % reduction
Available P loss (kg P ha^{-1})	$3x 10^{-2}$	8×10^{-3}	73 % reduction
TON (mg Ns^{-1})	1.28	0.08	94 % reduction
Soluble phosphate (ug Ps^{-1})	0.72	0.16	78 % reduction
Isoproturon	0.011ugs^{-1}	Not detected	100 % reduction

Table 10. Effect of soil tillage on soil erosion and diffuse pollution

Comparison of herbicide and nutrient emissions from 1991 to 1993 on a silty clay loam soil. Plots 12 m wide were established and sown with winter oats in 1991 followed by winter wheat and winter beans. De-nitrification in anaerobic soil and nitrification in aerobic soil produce nitrous oxide, with the former being more important. As soil structure improves, the potential for creating anaerobic conditions and nitrous oxide emissions is reduced (Arah et al., 1991). Intensive soil cultivations break-down SOM producing CO_2 thereby lowering the total C sequestration held within the soil. Building SOM the adoption of CT, especially if combined with the return of crop residues, can substantially reduce CO_2 emissions (West and Marland, 2002). In the UK, where CT was used soil C was 8% higher compared to conventional tillage, equivalent to 285g SOM m^{-2}. In the Netherlands SOM was 0.5% higher using an integrated approach over 19 years, although this increase was also achieved because of higher inputs of organic matter (Kooistra et al., 1989). Murillo et al. (2004) in a long term experimentation, observed that in CT (0-10 cm depth) organic matter values have been reached close to the minimum content of 2% (1.1% organic C, Table 11) considered necessary for most agricultural practices carried out in European Occidental soils (Bullock, 1997). These are indeed moderate values, and would not justify the implementation of conservation tillage systems (aimed at achieving high surface organic matter content).

	Year			
Soil depth (cm)	**Treatment**	**2001 (November)**	**2002 (January)**	**2002 (March)**
0-5	CT	9.8*	9.3*	11.1*
	TT	8.1	8.1	8.6
5-10	CT	9.5*	9.6	10.2*
	TT	8.1	8.5	8.3
10-25	CT	6.5	5.9	8.5
	TT	6.7	6.4	7.6
25-40	CT	-	4.4	6.9
	TT	-	5.0	6.1

* Significant differences between treatments per year per depth

Table 11. Mean values of organic carbon in the soil treated by conservation tillage and traditional tillage for the years 2001 sunflower and 2002 (wheat)

After 12 years of integrated farming incorporating CT, the SOM content was 25% higher at 0–5 cm and overall from 0 to 30 cm, 20 % higher (El Titi, 1991). Similar increases in SOM in the upper surface layers were also found in a number of studies conducted throughout Scandinavia (Rasmussen, 1999, Paustian et al., 2000). With CT, there is a risk that SOM may be reduced below this surface layer, but no evidence for this was found in Sweden (Stenberg et al., 2000).The significant build up in SOC is well documented in long term experiments with conservation tillage.

4. 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 minimise the disruption of the soil's structure, composition and natural biodiversity, thereby minimising erosion and degradation, but also water contamination (Anonymous, 2001).

5. 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 (b) residual water passes down to groundwater and stream flow, not over the surface as runoff.
- Favour beneficial biological activity in the soil

CT 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, CT is practised on 45 million ha, most of which is in North and South America (FAO, 2001) but is increasingly being used in other semi-arid (Lal, 2000a) 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 (Wilkins, 2008). 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).

6. 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. Soil health refers to the soil's capacity to perform its three principal functions e.g. economic productivity, environment regulation, and aesthetic and cultural values. There is a need to develop precise objective and quantitative indices of assessing these attributes of the soil. Training of professional staff must include developing their capacities in interdisciplinary collaboration and interpersonal relations. Research programmes and activities need to do more to address the real-life problems of farmers, and to include farmers in the design and implementation of programmes relevant to their needs. Research methodologies should be standardized and information dissemination should be an indispensable component of any common tillage network programme to be developed.

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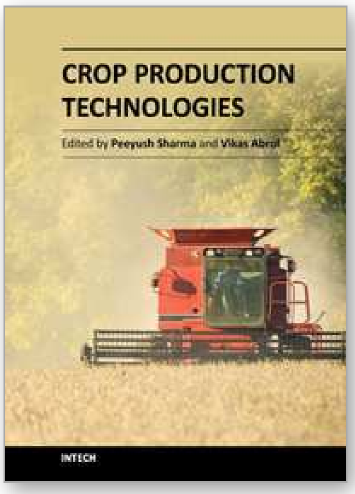

Crop Production Technologies
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Crop production depends on the successful implementation of the soil, water, and nutrient management technologies. Food production by the year 2020 needs to be increased by 50 percent more than the present levels to satisfy the needs of around 8 billion people. Much of the increase would have to come from intensification of agricultural production. Importance of wise usage of water, nutrient management, and tillage in the agricultural sector for sustaining agricultural growth and slowing down environmental degradation calls for urgent attention of researchers, planners, and policy makers. Crop models enable researchers to promptly speculate on the long-term consequences of changes in agricultural practices. In addition, cropping systems, under different conditions, are making it possible to identify the adaptations required to respond to changes. This book adopts an interdisciplinary approach and contributes to this new vision. Leading authors analyze topics related to crop production technologies. The efforts have been made to keep the language as simple as possible, keeping in mind the readers of different language origins. The emphasis has been on general descriptions and principles of each topic, technical details, original research work, and modeling aspects. However, the comprehensive journal references in each area should enable the reader to pursue further studies of special interest. The subject has been presented through fifteen chapters to clearly specify different topics for convenience of the readers.

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