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Tillage methods related to soil and water conservation in south Asia

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Abstract

Research on different tillage systems and their role in soil and water conservation in south Asia is reviewed. Tillage has shown marked influence on soil hydraulic characteristics and to some extent on soil chemical and biological properties particularly organic matter cycling. The importance of conservation tillage in reducing runoff, soil loss and in ensuring sustainable agricultural production in the region is emphasized. The role of other tillage practices, for example contour cultivation, contour bunding, terraces and tied ridging, in increasing the profile water storage is discussed.

Introduction

For sustained agricultural production, a tillage practice that optimizes soil conditions for seed germination, seedling emergence, establishment and subsequent growth of crops is important. Short-term objectives in tilling soil usually include: seed-bed preparation to optimize soil moisture and temperature, eradication of weeds in order to minimize competition with crops, reduction of impedance to roots in order to enhance root proliferation and development, and minimization of energy input. The long term objectives, as indicated by Lal (1979), should include "maintenance of soil productivity over long periods of time through adequate soil and water conservation, by maintaining soil organic matter at a high level, and by preserving soil structure and pore stability".

In the past, farmers, including those in South Asia, have tilled the land with the prime objective of increasing crop production. In recent years emphasis in soil tillage has, in addition to increasing crop productivity, included the concept of conservation tillage that ensures reduction in soil erosion through

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maintenance of at least 30% of the soil surface covered by residue (Mannering et al., 1987).

The principal tillage systems in south Asia are the traditional, conventional and in a few areas, particularly research farms, reduced tillage. Traditionally, tillage in most small farm holdings is done with animal drawn implements on flat or gently rolling land. It often involves plowing, harrowing and intercultivation to remove weeds and break soil crusts, especially at the early stages of plant growth in order to improve the infiltrability of the soil. For example, in India the non-inverting 'desi' plow is a wooden or an iron plow consisting of a stick with a hardened point for superficial tilling of the soil.

The plowing operation of this tool may in a sense be considered as reduced tillage when compared with the conventional tractorized tillage that involves a lot of soil disturbance and consumption of energy. Other special tillage tools are the 'bakhar', which is a blade harrow used for smoothing the soil surface and also for weed control. The conventional tillage operations are found mostly in the irrigated areas, where these operations usually involve mechanized plowing, chiselling, harrowing and intercultivation using tractors.

Even though a number of studies have established at many research stations the advantages and therefore the desirability of conservation tillage in south Asia, the major drawback hindering the adoption of conservation tillage at the farm level is the use of crop residues to feed animals and to construct fences and buildings. In this paper, we review some of the studies relating tillage and its contribution to soil and water conservation in south Asia.

Conventional tillage and soil water conservation

Tillage systems modify soil conditions (physical, chemical and biological) in the rhizosphere. The primary modification of the rhizosphere is due mainly to the cutting and inversion action of primary tillage that results in a reduction of bulk density and an increase of macropores in soil. As a consequence, the hydraulic properties of soil and therefore the soil's capabilities of conserving or losing water are usually modified by tillage. In this regard, deep tillage has been found by a number of researchers in south Asia to decrease soil bulk density and penetration resistance, to increase the proportion of macropores in soil and therefore the profile water storage e.g. Klaij (1983), Vittal et al. (1983), Chaudhary et al. (1985), Prihar et al. (1986). The studies of Reddy et al. (1977) and Chaudhary et al. (1985) indicate further that reduction in the bulk density of the soil induced deep and prolific root growth of crops thus resulting in better utilization of stored water in the profile (Table 1). In terms of the effect of tillage on the hydraulic characteristics of soil, studies conducted in Bangladesh by Rahman and Islam (1989) indicate that the cumulative infiltration rates of flood plain sandy loam soil were 28.2 mm h^{-1}, 46.5 mm h^{-1}, 72.6 mm h^{-1}, and 173.2 mm h^{-1} for no tillage, 7.5 cm, 15.0

Table 1
Data on soil properties, root growth and yield during kharif (rainy) season (mean of 2 years)

Crop	Tillage operation	Water intake rate ($cm\ h^{-1}$)	Hydraulic conductivity ($cm\ h^{-1}$)	Mean depth of root penetration (cm)	Dry weight of roots (g)	Grain yields ($kg\ ha^{-1}$)
Castor	Shallow	3.8	3.2	24.6	7.4	8.3
	Deep	6.0	5.2	45.7	13.1	10.9
Redgram	Shallow	3.7	3.5	22.1	6.4	9.1
	Deep	5.6	6.1	38.2	12.6	11.8
Groundnut	Shallow	3.2	2.1	13.7	2.2	6.4
	Deep	5.1	4.0	20.8	3.6	8.6
Pearl millet	Shallow	3.0	2.3	19.4	3.2	9.9
	Deep	4.9	4.2	28.6	4.8	12.9

Source: Reddy et al. (1977).

Table 2
Cumulative infiltration equations and correlation coefficients as influenced by different tillage treatments

Locations	Tillage depth	Cumulative infiltration equation *$I=at^n$		Correlation coefficient (r)
		a	n	
Sonatala	No tillage	0.387	0.654	0.998**
	7.5 cm	1.133	0.573	0.988**
	15.0 cm	1.493	0.582	0.991**
	22.5 cm	2.787	0.583	0.984**
Modhupur	No tillage	0.222	0.708	0.996**
	7.5 cm	0.291	0.729	0.996**
	12.5 cm	0.482	0.745	0.990**
	17.5 cm	0.786	0.712	0.984**
	22.5 cm	1.256	0.644	0.983**

Source: Rahman and Islam (1989).
*I, cumulative infiltration in cm.
t=elapsed time in minutes.
**, significant at 1% level.

cm, and 22.5 cm tillage depth treatments, respectively. Their infiltration characteristics for various tillage on two soils were very well described by Kostiakov's (1932) infiltration equation (Table 2). Other researchers in India, e.g. Tamhane and Tamboli (1955), Moshin and Alam (1966), Pandey, and Alam (1968) and Bhushan et al. (1973), have shown increased hydraulic conductivity of a seedbed as a result of increased porosity and aggregation (all attributes of changes in soil structure) when soils are plowed deeply.

In addition, tillage systems change the soil surface conditions, particularly in crusted soils, such that infiltration is enhanced with the resultant reduction in runoff. Consequently, profile water storage is optimized. Krishnamoorthy (1976) indicates that using a tooth harrow 1 or 2 days after seeding on ridges to break crusts is very effective. Furthermore, shallow cultivation used as secondary tillage (cultivation practice executed after seeding a crop) breaks surface crust and may create a 'dust mulch' to reduce soil evaporation. In years when the onset of rainfall is erratic, shallow tillage of crusted soils can also reduce seasonal runoff.

Tillage and soil management

The prime objective of both tillage and soil management is the maintenance of optimum soil conditions for crop production. This implies that the tillage and soil management systems employed should ensure a sustainable crop production without deterioration of the resource base. Soil management includes, among other things, water entrapment systems that enhance in situ soil water conservation and conservation tillage practices such as contour cultivation, surface and vertical mulch on gently sloping areas, mechanical and vegetative barriers e.g. contour and graded bunding, conservation ditching on moderately sloping areas and bench terracing on steep slopes.

There are a number of tillage systems that aim at either retarding runoff flow rate, in order to permit more water to infiltrate, or increasing the soil surface roughness or configuration, in order to pond water temporarily to prolong the time available for infiltration, and thereby reduce runoff. To achieve this, a system commonly used, particularly in parts of Africa and to a lesser extent in south Asia, is tied ridging, which aims at damming all or some of the furrows created during ridging at regular intervals so that part or all of the excess water infiltrates to increase the water storage of the soil profile. A common approach in south Asia is to construct contour bunds which are earthen bunds located at regular height intervals and laid out on the contour. Such contour bunds are similar to 'level terraces', 'ridge type terraces' or 'absorptive type terraces' (Gupta et al., 1971). Contour bunds reduce erosion by dividing long slopes into shorter sections. Theoretically, these bunds should increase soil profile water storage by controlling runoff and allowing ample time for water to infiltrate into the soil profile. Therefore runoff water that would normally be lost to the watershed stagnates behind these bunds up to spillway level. Practically, water stagnation and restricted drainage, within sizable areas, within fields, during the rainy season, has been found to decrease grain yields by up to 53% for pearl millet, and 45% for maize compared with yields measured from areas not affected by bunds (ICRISAT 1975–1976). However, in studies conducted from 1978 to 1982 to assess the effect of contour bunding on crop production, Pathak et al. (1986) found that well-designed contour bunds on Alfisols in India conserved soil and water effectively and were more efficient than other land management systems (Table 3). Water spreading systems as described for Pakistan (National Academy of Science, 1974) and the contour bund system widely used in India (Gupta et al., 1971), both serve to control flood and conserve water even though in the latter case the emphasis is on flood- and erosion-control and that water is kept in place as far as possible rather than diverted to a different area. However, raised bed cultivation (locally known as BUN) in the North Eastern Hills (NEH) of India has been found to result in extensive soil loss of 40–50 t ha^{-1} year^{-1} (Singh et al., 1985). Cultivation of crops on slopes with contour bunds and lack of maintenance of these bunds results in soil loss of about 68 t ha^{-1} year^{-1}. Similarly, pineapple, widely grown along the slope in the region, re-

Table 3
Grain yield, runoff and soil loss from different land-management systems on Alfisol watersheds with slopes greater than 1.5%, ICRISAT Center (1981–1984)

Land-management system	Crop	Grain yield (kg ha^{-1})	Runoff (mm)	Soil loss (t ha^{-1})
Broadbed and furrow[1]	Sorghum/ pigeonpea	2740 880	289	3.61
	Pearl millet/ pigeonpea	2400 900		
Contour bund[1]	Sorghum/ pigeonpea	2520 710	75	0.97
	Pearl millet/ pigeonpea	2230 730		
Modified contour bund with gated outlet[1]	Sorghum/ pigeonpea	3020 970	160	0.92
	Pearl millet/ pigeonpea	2730 1010		
Traditional flat with field bunds[2]	Sorghum/ pigeonpea	380 220	256	4.79
	Pearl millet/ pigeonpea	470 210		

Source: Pathak et al. (1986).
[1]Treatment with recommended crop management practices which implies the use of improved variety, cropping system, chemical fertilizer and other practices for weed, pest and insect control.
[2]Treatment with traditional management practices which implies the use of traditional variety, cropping system, farmyard manure, implements and other practices.

sults in soil loss from 24 to 63 t ha^{-1} $year^{-1}$. Cultivation on bench terraces in certain areas of Nagaland, Manipur and land management systems using bench terraces in Sikkim in India have been widely adopted by farmers.

Simple soil conservation measures such as bench terraces, contour bunds, and half moon terraces have been found to reduce soil loss to 2–3 t ha^{-1} $year^{-1}$ if properly maintained in mixed land use systems (Singh et al., 1985).

Contour cultivation, in which crops are grown at prescribed spacing on the contour, has the effect of intercepting and retarding the flow rate of runoff in order to allow more water to infiltrate. For example contour cultivation on alluvial soils with a 2.2% slope reduced soil loss by 28% and runoff by 61% compared with cultivation up and down the slope (Bhatia and Chaudhary, 1977). On an 8% slope at Dehra Dun in India, contour cultivation was found to reduce runoff from 54.1 to 41.2% and soil loss from 28.5 to 19.3 t ha^{-1} (Tejwani, 1981).

Conservation tillage and soil water conservation

Under certain circumstances, tillage implements compact soil particularly under plowshare, and smear or puddle soil when cultivation operations are conducted in the plastic state. Furthermore, the high energy demands of conventional tillage operations in a world where energy is increasingly becoming expensive, has necessitated a re-thinking of its use. Increasingly 'conservation tillage' systems that lower energy inputs and prevent the structural breakdown of soil aggregates would have to be adopted in south Asia and other developing countries if the deleterious effects of conventional tillage are to be minimized or eradicated altogether. A system is classified as conservation tillage when it includes (Lal, 1989), crop residue as mulch, conserves water and soil, maintains organic matter level and soil structural stability, requires minimum use of chemical amendments and pesticides, does not pollute the environment and maintains an economic level of productivity. Reduced tillage has been reported by Gupta and Gupta (1986) to improve soil environment (Table 4). In studies to determine the effect of tillage and surface mulching on physical properties, growth and yield of cowpeas grown in western Rajasthan, India, Gupta (1987) found that reduced soil tillage (one disking with a disk harrow) for 3 years significantly increased the final organic matter content from 0.27 to 0. 35%, decreased the gravimetric moisture content at −0.01 MPa from 11.0 to 10.6%, soil bulk density from 1.58 to 1.52 Mg m^{-3} soil strength from 9.9 to 5.9 kg cm^{-2} and steady state infiltration rate from 15.6 to 10.8 cm h^{-1}. Under all the tillage conditions (i.e. no disking, one disking and three diskings), mulching the inter-row spaces with weeds at the rate of 6 t ha^{-1} increased the organic matter content by 10–25%, infiltration rate by 10–20% and decreased bulk density by 0.05–0.07 Mg m^{-3} and soil strength by 1.25–3.20 kg cm^{-2}. Mulching significantly increased grain

Table 4
Soil environment as affected by mulching and discing (mean values of 1982 and 1983)

Treatment	Bulk density ($g\ cm^{-3}$)	Soil strength ($kg\ cm^{-2}$)	Mean moisture content (%)	Mean maximum temperature (°C)
No discing, no mulch	1.54	2.9	5.8	42.0
No discing, mulch	1.49	2.4	7.0	37.6
One discing, no mulch	1.39	2.2	6.1	41.2
One discing, mulch	1.37	1.5	7.5	37.6
Three discing, no mulch	1.36	2.3	6.3	40.2
Three discing, mulch	1.34	1.7	7.7	36.6
LSD (0.05),	0.02	0.15	0.1	0.8
discing, mulching	0.02	0.12	0.42	0.6
Discing×mulching	NS	0.21	NS	NS

Source: Gupta and Gupta (1986).

yield of cowpeas 3 fold compared to no tillage, 25 to 45% with reduced tillage and 25 to 40% with excessive tillage.

Tillage implements and soil water conservation

Different tillage methods and implements are known to differ in their effect on soil moisture conservation. A major factor that influences soil moisture storage in the crop root-zone is the tillage implement. Moisture conservation is important in the growing season, hence conservation is of prime importance in the preparation of post-rainy season seed-bed in unirrigated areas (Michael, 1990).

Singh et al. (1978) evaluated and compared the effect of some modern and traditional tillage implements on soil-moisture storage and crop yield. Deep ploughing with a tractor drawn mould-board and a tandem disc plough helped in increasing soil moisture in the upper 30 cm soil layer, compared with shallow ploughing with either cultivar or country plough. At lower a depth (30–50 cm), there was not much variation in soil when different tillage implements were used. Chiselling increased water transmission. So far as rice yields were concerned, ploughing twice with a country plough followed by planking, maximized rice grain.

Khan et al. (1984) found that the mean weight diameter and geometric mean diameter of aggregates were higher under mould-board plough treatments than under wedge-ploughing or rotary tillage treatments. Darra and Sharma (1970) reported that the implements e.g. desi plough, tractor cultivation and harrowing, mould-board plough and bakhar plough, when applied after irrigation, increased water stable aggregates greater than 0.5 mm diameter over fallow (control).

A wooden country plough followed by a three tyned cultivator was found to be the best implement in keeping the soil in good physical condition (Shrivastava and Alam, 1967). Bhagat and Tamboli (1966) also found that mechanical composition, volume expansion, true and apparent specific gravity, percentage of pore space and Atterbergs constant remained unchanged while the water holding capacity, sticky point and rate of percolation increased as a result of tillage implements. The percentage of aggregates less than 0.21 mm in diameter decreased significantly. No significant change in hydrochloric acid extract constituents of soil, total soluble slots, pH and cation exchange capacity, were observed. However, the organic matter and total nitrogen contents were reduced. Bacterial count and nitrifying capacity increased while nitrogen fixing power decreased.

Naravani and Sirohi (1978) indicated that aggregation was highest after the desi plough was used in sandy loam soils. The effects on structure of sandy loam soils of ploughing with desi and mould-board ploughs and harrowing with bakhar sweeps and disc harrows were studied by determining the mean weight diameter of water stable aggregate by wet sieve analysis after various tillage treatments.

Malik et al. (1987) reported that primary tillage with different implements

Table 5
Effect of primary tillage treatments before rainy season sowing on soil physical characteristics and soil moisture storage in 120 cm profile

Tillage practice	No. of applications	Depth of tillage (cm)	Initial infiltration rate (cm h^{-1})	Bulk density (g cm^{-3})	Moisture storage (mm per 120 cm)
Mould board plough (TD)*	One	30.0	7.6	1.35	184
Disc plough (TD)	Two	12.5	5.7	1.25	176
Country plough (BD)**	One	10.0	5.2	1.45	161
Country plough (BD)	Two	12.0	5.8	1.43	165

Source: Malik et al. (1987).
TD*, tractor drawn; BD**, bullock drawn.

has a significant effect on the infiltrability and water storage of loamy sand soil (Table 5).

Conclusions

We conclude that research in south Asia, particularly in India, has shown that deep tillage modifies the hydraulic characteristics of soil resulting in reduced runoff and increased infiltration and therefore increased profile water storage for crop growth. In addition tillage modifies the soil surface conditions in crusted soils, thus breaking the 'throttle' at the surface and enhancing water infiltration. Tillage systems like contour cultivation, tied ridging, contour bunding, terracing are effective in retarding runoff rate and ensuring adequate time for infiltration to occur. Conservation tillage systems have proved to be effective at research stations in the region and would have to be extended to farmers. The major drawback with its adoption in south Asia is the use of crop residues to feed animals and also unavailability of bullock drawn equipment to sow seeds precisely into residue left on soil surface.

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