HAMBLIN, A.P. 1981. Filter-paper method for routine measurement of field water potential. *Journal of Hydrology* **53**, 355–360.
LAL, R. 1974. Soil temperature, soil moisture and maize yield from mulched and unmulched tropical soils. *Plant and Soil* **40**, 129–143.
LARSON, W.E., BURROWS, W.C. & WILLIS, W.O. 1960. Soil temperature, soil moisture and corn growth as influenced by mulches of crop residues. *Transactions 7th International Congress Soil Science, Vol 1*, pp. 629–637. Madison, WI.
LEWIS, W.M. & PHILLIPS, J.A. 1976. Double-cropping in Eastern United States. In: *Multiple Cropping* (ed. R.I. Papendick, P.A. Sanchez & G.B. Triplett), pp. 41–50. American Society of Agronomy, Madison, Wisconsin.
McLEOD, S. 1975. Studies on wet oxidation procedures for the determination of 'Organic C' in soils. In: *Notes on Soil Techniques 1973*, pp. 73–79. CSIRO Division of Soils, Adelaide.
SANFORD, J.O., MYHRE, D.L. & MERWINE, N.C. 1974. Double-cropping: aerial seeding of wheat before soybean harvest. *Mississippi Agricultural & Forestry Experiment Station Research Report* **37** (10), 1, 8.
STACE, H.C.T., HUBBLE, G.D., BREWER, R., NORTHCOTE, K.H., SLEEMAN, J.R., MULCAHY, M.J. & HALLSWORTH, E.G. 1968. *A Handbook of Australian Soils.* Rellim Technical Publications, Glenside, South Australia.
TISDALL, J.M. & ADEM, H.H. 1986. The effect of reduced tillage of an irrigated silty soil and of a mulch on seedling emergence, growth and yield of maize (*Zea mays*) harvested for silage. *Soil and Tillage Research* **6**, 365–375.
TISDALL, J.M. & ADEM, H.H. 1988. An example of Custom Prescribed Tillage in south-eastern Australia. *Journal of Agricultural Engineering Research* **39**, 23–32.
VAN WIJK, W.R., LARSON, W.E. & BURROWS, W.C. 1959. Soil temperature and the early growth of corn from mulched and unmulched areas. *Soil Science Society of America Proceedings* 23, 428–434.

Performance of low-draft tillage implements on a hard setting Alfisol of the SAT in India

N.K. Awadhwal & G.D. Smith[1]

Abstract. Four bullock-drawn tillage implements (mouldboard plough, chisel plough, sweeps, and shovels) were evaluated on a hard-setting Alfisol. Measurements included draft requirement, bulk density, cone index, soil crust strength, water content of the plough-layer and crop yield. Changes in bulk density and cone index due to tillage decreased with time and were negligible by the end of the growing season. After tillage with a mouldboard plough the crust was stronger than after tillage with other implements. The shovel cultivator enabled the soil to store more water, and required least draft per unit effective area of cut.

INTRODUCTION

STUDIES of farming in the tropics have sometimes found that systems with reduced or no tillage have advantages over those based on tillage (Lal, 1976; Jones & McCown, 1983). However, farmers on Alfisols in the semi-arid tropics rely on tillage, and results of research often support their practice (Charreau, 1972; Nicou & Chopart, 1979; Vittal *et al.*, 1983; El-Swaify *et al.*, 1985). The benefits of tillage are usually attributed to increased roughness and porosity in the surface soil, increased infiltration of water, better crop establishment, and root growth through more porous and weaker soil. Hence tillage is used to remedy poor soil structure. The effects of tillage are short-lived on soil that forms a surface seal under rain or in which the tilled layer becomes hard or compacted after a few cycles of wetting and drying. In Australia this compaction and hardening, referred to as 'hard setting' (Northcote *et al.*, 1975; Mullins *et al.*, 1987), is used as a criterion for soil classification. The hard setting tendency in the surface of some Alfisols may be aggravated by excessive tillage. For example, Awadhwal & Thierstein (1984) found that intensive tillage with a mouldboard plough increased crusting.

Farmers will continue to rely on tillage until acceptable reduced tillage systems are available. In the tropics farmers generally depend on human labour and draft animals (usually oxen) for most farm operations. They have difficulty in tilling their land, as they must rely on their animals for draft. There has been some progress in the development of light implements (Krause *et al.*, 1984). Research is needed to determine which implements require least draft and which have best and longest-lasting effects on soil structure. This paper reports a comparison of four bullock-drawn implements.

[1]Resource Management Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh 502 324 India.

MATERIALS AND METHODS

Four low-draft bullock-drawn implements were compared on a sandy loam Alfisol, at ICRISAT Centre, in experiments during the rainy season and afterwards. The soil lacks structural development because the prevailing clay minerals (kaolin, with a small proportion of 2:1 clay and sesquioxides) are inactive and the soil contains little (< 0.5%) organic carbon. Its pH and EC (1:2.5, H_2O suspension) were 6.0 and 0.1 mS cm^{-1}, respectively. The other major characteristics of the soil are given in Table

Table 1. Major characteristics of the Alfisol at ICRISAT Centre

	Size distribution (%) of particles < 2 mm			Stone* (%)	Water retention			
Depth (cm)	< 2 μm	2–20 μm	20–200 μm	> 2 mm	1/3-bar (gravimetric %)	15-bar (gravimetric %)	CEC (Meq 100 g^{-1})	Base saturation (%)
0–5	14.3	6.4	79.3	17	16.2	4.3	4.8	74
5–20	27.8	5.5	66.7	17	20.0	10.4	8.2	64

*By weight of total soil.

1. The experiments were organized in a randomized-block design with four treatments comprising primary tillage with shovel cultivator, chisel plough, sweep cultivator, and mouldboard plough in combination with a ridger. The rainy season experiments in 1985 and 1986 had six replications, and sorghum was grown. The post-rainy (dry) season experiment conducted in 1985 had nine replications without a crop to monitor soil water in uncropped soils. The shovel, chisel, sweeps and mouldboard plough had a width of cut of 35, 40, 150 and 220 mm, respectively, and their specifications were in accord with those of the Indian National Bureau of Standards (1986).

In the experimental plots furrows 50 cm wide were marked at a spacing of 1.5 m with a pair of ridgers, and the tillage treatments were imposed on a 1-m wide strip (broadbed) between the furrows (Kampen, 1982). Shovels and sweeps, covering an effective width of 1 m, were used in sets of five. Chisel ploughs were used in pairs in two passes to cover the required width. In the first pass chisels were spaced 30 cm apart and in the second pass at 90 cm apart. For tillage with the mouldboard plough the broadbed was split in the middle with a ridger followed by tillage with a pair of left-hand and right-hand mouldboard ploughs in two passes. In the first pass the ploughs were spaced 60 cm apart and in the second pass at 100 cm apart. After imposing the primary tillage treatments, secondary tillage with a blade harrow was carried out on all treatments. Finally, a pair of ridgers with a chain attached was used to shape the broadbeds and deepen the furrows. Sorghum was sown in late June with a bullock-drawn mechanical planter. Inter-row cultivation with duck-foot sweeps 22 days after sowing was followed by hand weeding.

Draft forces were measured during tillage by a spring-type mechanical pull dynamometer. The distribution of aggregate size in the 0–5 cm layer of soil was determined with a sieve shaker (Soil Test). Bulk density was determined to a depth of 20 cm using a core sample of 140 cm^3 at 7 cm increments. Three determinations, which were subsequently averaged, were made on each replication of all the treatments. Moisture content of these samples was also determined gravimetrically. Penetration resistance was measured to a depth of 20 cm using a recording field penetrometer (Eijkelkamp penetrograph) fitted with a 1 cm relieved cone having a 60° apex. Five penetrations per plot were made and the chart recordings read at 5 cm intervals. The five readings per plot were then averaged. A pocket penetrometer (Soil Test) was used to determine the strength of the soil crust. The yields of grain and the total dry matter were assessed from plants harvested by hand from a 45 m^2 area (3 beds of 10 m length) from each replication of all treatments.

RESULTS AND DISCUSSION

Draft requirements

In both rainy-season experiments soil was tilled at the optimum water content (8–9% gravimetric) for tillage. The average pull required for a set of two mouldboard ploughs used in a pair, working to 10 cm and with an effective width of 40 cm, was 180 kg. A set of five shovels working to 10 cm and with an effective width of 1 m required a 190-kg pull. A pair of chisel ploughs penetrating to 15 cm with an effective width of 50 cm required a 200-kg pull. A set of five sweeps working to 5 cm with an effective width of 1 m required a 117-kg pull. The pull requirement for the sweeps was significantly less ($P < 0.05$) than for the other implements, which were not significantly different from one another. However, the draft requirement calculated on the basis of unit effective area of cut (the product of depth of cut and effective width) of the shovel cultivator (0.19 kg cm^{-2}) was significantly ($P < 0.05$) less than that of sweeps (0.23 kg cm^{-2}), which was not significantly different from that of the chisel plough (0.26 kg cm^{-2}). The mouldboard plough required significantly more draft (0.45 kg cm^{-2}) than did the other implements.

Bulk density

The effect of treatments on bulk density was essentially the same in both rainy-season experiments. Results only for the surface layer are considered because of the different depths of tillage (Table 2). The average bulk density of surface soil (0–7 cm) before tillage was 1.49±0.021 g cm^{-3}. One week after tillage, irrespective of the implement used, the average bulk density was 1.36±0.025 g cm^{-3}. The soil reverted to its original density in about 6 weeks, despite one inter-row cultivation. This recompaction was brought about by 180 mm of rain (three events) during 1985, and 204 mm of rain (four events) in 1986.

Table 2. Effect of tillage implements on bulk density (g cm^{-3}) in the 0–7 cm layer of the soil at ICRISAT Centre, during the rainy seasons of 1985 and 1986

Time of observation	Tillage implement					
	Shovel	Chisel	Sweeps	Plough	Mean	SE±
Before tillage*	1.49	1.51	1.50	1.49	1.49	0.021
1 week after tillage*	1.40	1.35	1.36	1.34	1.36	0.025
6 weeks after tillage**	1.50	1.51	1.49	1.57	1.51	0.081

*Based on the data for both years.
**Based on 1986 data only.

Cone index

The pattern of responses was the same in both years, and average cone indices, 1 week and 6 weeks after tillage, are presented in Table 3. Cone penetrometer measurements were made at a mean gravimetric water content close to 10%. The average cone index before tillage was 415 kPa in the 0–7 cm layer and 480 kPa in the 7–14 cm layer. Cone index increased with depth in all treatments. The soil in the 0–7 cm layer 1 week after tillage was significantly stronger ($P < 0.05$) after sweep tillage than after chisel tillage or mouldboard ploughing but was not significantly different from shovel-tillage. However, at 6 weeks only the soil that had been ploughed had a significantly smaller cone index. At 0–7 cm the soil that had been sweep-tilled was significantly stronger ($P < 0.05$) than that under all the other treatments. Either the sweeps had compacted this layer or, more likely, this larger index reflects the lack of soil disturbance at this depth.

Table 3. Effect of tillage implements on the cone index (kPa) of the soil at ICRISAT Centre, during the rainy seasons of 1985 and 1986

Depth (cm)	Tillage implement					
	Shovel	Chisel	Sweeps	Plough	Mean	SE±
1 week after tillage*						
0–7	72.5	63.7	85.2	48.2	67.4	7.1
7–14	205.3	150.4	250.4	152.8	189.6	15.4
SE±			13.8			
6 weeks after tillage*						
0–7	155.0	161.8	181.8	140.1	159.6	12.4
7–14	224.0	249.0	308.6	210.0	247.3	15.6
SE±			18.0			

*Based on the data for both years.

In 6 weeks the cone index had more than doubled in the 0–7 cm layer and increased in the range of 9–66% at 7–14 cm. By the end of the crop-growing season (October) the cone index under all treatments had reverted to the original values. These results demonstrate the hard-setting nature of this soil.

Crust strength

The strength of the crust 4 days after planting, measured on and between seeded rows, is presented in Table 4. In the inter-row zone the crust was significantly stronger ($P < 0.01$) after the mouldboard plough than after the other treatments. This may have been because it inverted soil containing more clay. However, there was no difference in the crust strength measured on rows under different treatments. A reason for this could be that the press wheels of the planter used for sowing the test crop, while pressing soil on the seeded rows, increased the strength of the crust.

Table 4. Effect of tillage implements on crust strength (kPa), measured 4 days after sowing at ICRISAT Centre, during the rainy seasons of 1985 and 1986

Crust strength	Tillage implement					
	Shovel	Chisel	Sweeps	Plough	Mean	SE±
1985						
In rows	214	219	217	243	227	13.3
Between rows	167	171	172	239	188	9.9
1986						
In rows	262	256	270	283	267	10.2
Between rows	196	201	200	281	219	9.2

Soil moisture

In all the four experiments water held in the top 20 cm layer was at a maximum in the shovel-tilled plots and at a minimum after chisel tillage. The differences in soil water content under different tillage treatments were statistically significant ($P < 0.05$) in the region of field capacity (Fig. 1). The differences were no longer significant by the time water content decreased to about half of the field capacity (Fig. 2). Improved water storage could have been due to more stable large-diameter pores or due to increased sur-

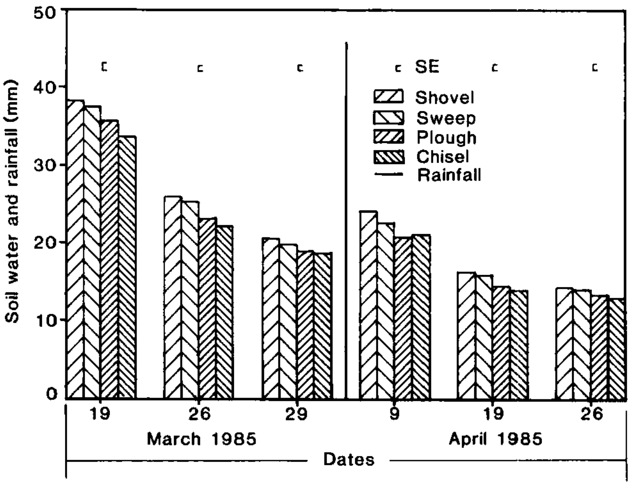

Fig. 1. Water held (mm) in 20 cm surface layer of Alfisol, ICRISAT Centre, rainy season, 1985 and 1986.

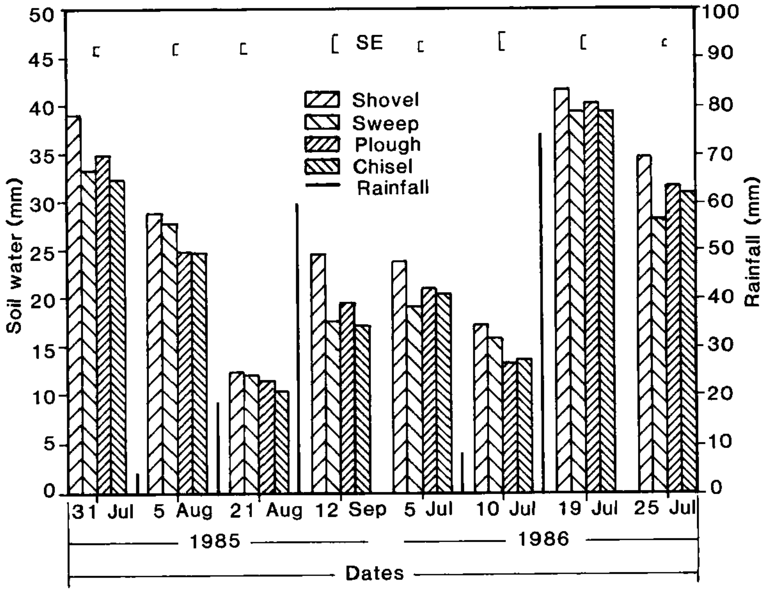

Fig. 2. Water held (mm) in 20 cm surface layer on Alfisol, ICRISAT Centre, summer 1985.

face roughness that trapped water. It was not due to differences in clod sizes after tillage because no significant differences were found in the size-distribution of dry clods.

Crop yield

The effects of tillage on grain yield (mean = 2 t ha^{-1}), and total dry matter produced (mean = 6 t ha^{-1}) were not significant.

CONCLUSION

(1) The different tillage implements had similar effects on bulk density and strength of the 0–7 layer, despite differences in working depths and draft requirement.

(2) Effects of tillage with the implements tested did not persist through the growing season. Bulk density reverted more rapidly than strength.

(3) The mouldboard plough aggravates the problem of crusting on this soil.

(4) The shovel cultivator is superior to other implements because it increases storage of water in the soil. It covers a wider strip in comparison with the chisel and mouldboard ploughs for almost the same pull requirement and has the least draft on the basis of unit effective area of cut.

REFERENCES

Awadhwal, N.K. & Thierstein, G.E. 1984. Evaluation of tillage methods for light-textured Alfisols of the semi-arid tropics. *Journal of Agricultural Engineering (ISAE)* **21**(1–2), 44–54.

Charreau, C. 1972. Problèmés poses par l'utilisation agricole des sols tropicaux par des cultures annuelles. *Agronomie Tropicale* **27**, 905–929.

El-Swaify, S.A., Pathak, P., Rego, T.J. & Singh, S. 1985. Soil management for optimized productivity under rainfed conditions in the semi-arid tropics. *Advances in Soil Science* **1**, 1–64.

Jones, R.K. & McCown, R.L. 1983. *Research on a no-till, tropical legume-ley farming strategy.* Research report S/10. Commonwealth Scientific and Industrial Research Organization, Division of Tropical Crops and Pastures. Townsville, Australia.

Kampen, J. 1982. *An approach to improved productivity on deep Vertisols. Information bulletin no. 11.* International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh 502 324, India.

Krause, R., Lorenz, F. & Hoogmoed, W.B. 1984. *Soil tillage in the tropics and subtropics.* Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, pp. 77–280, Eschborn.

Lal, R. 1976. No-till effects on soil properties under different crops in western Nigeria. *Soil Science Society of America Journal* **40**, 762–768.

Mullins, C.E., Young, I.M., Bengough, A.G. & Ley, G.J. 1987. Hard setting soils. *Soil Use and Management* **3**, 79–83.

National Bureau of Standards, 1986. *Indian standards for soil working equipment.* National Bureau of Standards, New Delhi.

Nicou, R. & Chopart, J.L. 1979. Root growth and development in sandy, and sandy clay soils of Senegal. In: *Soil Physical Properties and Crop Production in the Tropics* (ed. D.J. Greenland & R. Lal), John Wiley, New York.

Northcote, K.H., Hubble, G.D., Isbell, R.F., Thompson, C.F. & Bettany, E. 1975. *A description of Australian soils.* CSIRO, Australia.

Vittal, K.P.R., Vijayalakshmi, K. & Rao, U.M.B. 1983. Effect of deep tillage on dryland crop production in red soils of India. *Soil & Tillage Research* **3**, 377–384.