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

N.K. Awadhwal & G.D. Smith

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 semiarid 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.

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, H₂O suspension) were 6.0 and 0.1 mS cm⁻¹, respectively. The other major characteristics of the soil are given in Table

penetrometer (Eijkelkamp penetrograph) fitted with a measured to a depth of the treatments. Moisture content of these samples was also plot were made and the chart recordings read at 5 cm intervals. The five readings per plot were then averaged. consequently averaged, were made on each replication of all treatments. Moisture content of these samples was also plot were made and the chart recordings read at 5 cm intervals. The five readings per plot were then averaged.

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 \((0.19 \text{ kg cm}^{-2})\) was significantly \((P < 0.05)\) less than that of sweeps \((0.23 \text{ kg cm}^{-2})\), which was not significantly different from that of the chisel plough \((0.26 \text{ kg cm}^{-2})\). The mouldboard plough required significantly more draft \((0.45 \text{ kg cm}^{-2})\) 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 \((0–7 \text{ cm})\) 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.

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.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>&lt; 2 μm</th>
<th>2–20 μm</th>
<th>20–200 μm</th>
<th>&gt; 2 mm</th>
<th>Water retention 1/3-bar (gravimetric %)</th>
<th>15-bar (Meq 100 g(^{-1}))</th>
<th>CEC (Meq 100 g(^{-1}))</th>
<th>Base saturation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–5</td>
<td>14.3</td>
<td>6.4</td>
<td>79.3</td>
<td>17</td>
<td>16.2</td>
<td>4.3</td>
<td>4.8</td>
<td>74</td>
</tr>
<tr>
<td>5–20</td>
<td>27.8</td>
<td>5.5</td>
<td>66.7</td>
<td>17</td>
<td>20.0</td>
<td>10.4</td>
<td>8.2</td>
<td>64</td>
</tr>
</tbody>
</table>

*By weight of total soil.

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 \((0.19 \text{ kg cm}^{-2})\) was significantly \((P < 0.05)\) less than that of sweeps \((0.23 \text{ kg cm}^{-2})\), which was not significantly different from that of the chisel plough \((0.26 \text{ kg cm}^{-2})\). The mouldboard plough required significantly more draft \((0.45 \text{ kg cm}^{-2})\) than did the other implements.

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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

<table>
<thead>
<tr>
<th>Time of observation</th>
<th>Shovel</th>
<th>Chisel</th>
<th>Sweeps</th>
<th>Plough</th>
<th>Mean</th>
<th>SE±</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before tillage*</td>
<td>1.49</td>
<td>1.51</td>
<td>1.50</td>
<td>1.49</td>
<td>1.49</td>
<td>0.021</td>
</tr>
<tr>
<td>1 week after tillage*</td>
<td>1.40</td>
<td>1.35</td>
<td>1.36</td>
<td>1.34</td>
<td>1.36</td>
<td>0.025</td>
</tr>
<tr>
<td>6 weeks after tillage**</td>
<td>1.50</td>
<td>1.51</td>
<td>1.49</td>
<td>1.57</td>
<td>1.51</td>
<td>0.081</td>
</tr>
</tbody>
</table>

*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

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Shovel</th>
<th>Chisel</th>
<th>Sweeps</th>
<th>Plough</th>
<th>Mean</th>
<th>SE±</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 week after tillage*</td>
<td>0–7</td>
<td>72.5</td>
<td>63.7</td>
<td>85.2</td>
<td>48.2</td>
<td>67.4</td>
</tr>
<tr>
<td></td>
<td>7–14</td>
<td>205.4</td>
<td>150.4</td>
<td>250.4</td>
<td>152.8</td>
<td>189.6</td>
</tr>
<tr>
<td>SE±</td>
<td></td>
<td>13.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 weeks after tillage**</td>
<td>0–7</td>
<td>155.0</td>
<td>161.8</td>
<td>181.8</td>
<td>140.1</td>
<td>159.6</td>
</tr>
<tr>
<td></td>
<td>7–14</td>
<td>224.0</td>
<td>249.0</td>
<td>308.6</td>
<td>210.0</td>
<td>247.3</td>
</tr>
<tr>
<td>SE±</td>
<td></td>
<td>18.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*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

<table>
<thead>
<tr>
<th>Crust strength</th>
<th>Shovel</th>
<th>Chisel</th>
<th>Sweeps</th>
<th>Plough</th>
<th>Mean</th>
<th>SE±</th>
</tr>
</thead>
<tbody>
<tr>
<td>1985 In rows</td>
<td>214</td>
<td>219</td>
<td>217</td>
<td>243</td>
<td>227</td>
<td>13.3</td>
</tr>
<tr>
<td></td>
<td>167</td>
<td>171</td>
<td>172</td>
<td>239</td>
<td>188</td>
<td>9.9</td>
</tr>
<tr>
<td>1986 In rows</td>
<td>262</td>
<td>256</td>
<td>270</td>
<td>283</td>
<td>267</td>
<td>10.2</td>
</tr>
<tr>
<td></td>
<td>196</td>
<td>201</td>
<td>200</td>
<td>281</td>
<td>219</td>
<td>9.2</td>
</tr>
</tbody>
</table>

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-
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 crust 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**


