Implement Development for SAT Alfisols

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Abstract

Field operations in Alfisols and related soils require timeliness and precision for the early establishment of a crop in the rainy season. Animal-drawn, multipurpose wheeled tool carriers (WTCs) have been found to be the most appropriate machinery for this purpose. Three designs discussed in this paper covered 1 ha in 3-4 hours for different tillage operations, and could be drawn by a pair of oxen of average size. A WTC fitted with a planter-and-fertilizer applicator, consisting of an inclined plate for seed metering and oscillating mechanisms for fertilizer metering and a double-shoe furrow opener, gave excellent results in sowing various crops, and covered 1 ha in 4-5 hours with an average draft of 1530 N (156 kgf) for four rows. A rolling crust breaker, developed to enhance seedling emergence through the surface crust, gave good results. Intensive primary tillage of Alfisols showed advantages in the early stages of crop growth, but they tended to disappear late in the season. Results of tillage studies conducted for 4 years indicate a need for further research to find out the comparative advantages of different intensities of primary tillage during the cropping season and off-season.

Introduction

As discussed elsewhere in this volume, Alfisols and related soils in the semi-arid tropics have certain inherent characteristics, such as low water-holding capacity, high erodibility, and a potential for excessive runoff, that are constraints in crop production under rainfed conditions. Alfisols are often very shallow and possess a subsurface layer of compacted soil that inhibits root development and water percolation. The loamy sand texture of the topsoil and predominance of kaolinite among the clay minerals make these soils structurally "inert" (Charreau 1977). Thus the noncracking topsoil becomes very hard when dry, making primary tillage possible only after good showers before the rainy season. Structural instability of these soils often causes crusting of the surface when rain alternates with dry periods. The formation of a crust subsequent to sowing can be a serious problem for the establishment of a crop with required plant density.

Alfisols therefore offer a considerable challenge regarding the development of farm machinery required for: tillage and seedbed preparation operations that make possible the early sowing of crops; the improvement of metering and placement of seed and fertilizer; the enhancement of seedling emergence in the event of crust formation; and the effective control of interrow weeds. The need to evaluate alternative tillage practice and to study the reaction of the soil to tillage tools, plant and soil interaction during plant establishment and early growth, and seedbed requirements were also recognized. This paper summarizes farm machinery development, and the results of selected experiments conducted on Alfisols, at ICRISAT Center.

Machinery Development

Multipurpose wheeled tool carriers (WTCs)

In the SAT, farmers mostly depend on human labor and draft animals (usually oxen) in their farm operations. In India a range of ox-drawn implements,

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such as a country plow, a blade harrow, a seeder with hand metering for two or three rows, and an inter-row weeding hoe are common everywhere. These implements are attractive to farmers because of their low purchase and maintenance costs, easy availability from local artisans, and minimal repair requirements. But they are slow in operation, are tiring to use, and often fail to give the precision required for intensive cropping.

After initial experience with traditional ox-drawn implements in farming systems research at ICRISAT Center, efforts were directed towards the development of multipurpose wheeled tool carriers. As the name implies, such a too[l c]arrier, drawn by oxen, asses, or mules, is capable of performing various field operations by the attachment of appropriate implements. The frame and linkages on the WTC have provisions for making vertical and lateral adjustments in the position of the implement with respect to the soil surface or the crop. An implement mounted on the WTC can be raised into a transport position, or lowered to operate in the soil, with a lever. A WTC provides stability in operation, comfort for the operator, and is designed to maintain the correct direction of travel in the field.

The first design of a WTC found to be promising

Figure 1. A Tropicultor with spring tines in use for seedbed preparation.

Figure 2. An Agribar being used for plowing on broadbeds with a set of left- and right-hand moldboard plows.

was the Tropicultor, already in use in some parts of West Africa. The Tropicultor was evaluated at ICRISAT Center and modified. Later, more work was done on matching implements to meet the operational requirements without undue stress on the oxen. The Tropicultor (Fig. 1) has a set of pneumatic wheels supporting a tubular frame, with a beam at the front and a square toolbar 1.7 m long at the rear. The toolbar is attached to the lifting linkages with removable pins such that its height from the ground can be varied. All implements are mounted on the toolbar with simple U-clamps. The Tropicultor can also be converted into a two-wheeled cart by mounting a cart attachment over the frame.

The Tropicultor was found to be very effective and useful for field operations in watershed areas at ICRISAT Center and in farmers' fields. However, its high purchase price has been a major constraint in its acceptance by Indian farmers. Subsequently, development of relatively low-cost tool carriers with comparable versatility and utility was initiated. The first low-cost design, the Akola Cart, was derived from an ox-drawn small cart popular in the Akola region of Maharashtra State in India. Its frame and wheels are made of wood, and a hollow, rectangular steel toolbar is attached to the frame. A lifting mechanism operated by a lever placed in the center raises or lowers the implement mounted on the toolbar. The arrangement for mounting implements on the toolbar is similar to that for the Tropicultor.

The second low-cost design is the Agribar (Fig. 2). It is made of steel and has a 1.7-m long square toolbar to which a beam is attached at right angles. The toolbar is supported on two wheels of 30 cm diameter. Implements mounted on the toolbar can be raised or lowered by operating a lever at each end of the toolbar one by one. Implements for the Agribar are the same as those used with the Tropicultor, and the manner of mounting is identical.

To compare the performance of these three WTCs, we measured the actual field capacity (the area covered in 1 hour), and the draft requirements for different operations. To enlarge the scope of the experiment, a 20.9 kW (28 hp) TE-type Bouyer tractor was also included in the study. Plot sizes varied from 271 to 688 m², because of the shape of the field.

For all field operations, the Tropicultor had greatest reliability (ICRISAT 1982). With the Akola Cart there were problems of frequent breakdowns because of failure of the wooden components. Similarly, the Agribar, at that stage in its development, was not strong enough to withstand the load of two normal-sized 225-mm wide moldboard plows or ridgers. Accordingly, smaller plows and ridgers were used on the Cart and the Agribar. Results obtained for the time required per ha for different operations (Table 1) showed that the Tropicultor was the most efficient. Because of the smaller plows used with the Akola Cart and the Agribar, plowing was done twice in the respective plots. For other operations the difference between the treatment in terms of time-saving was very small, often statistically nonsignificant ($P < 0.05$). The tractor did not show any advantage over the [illegible]nal-drawn machinery.

The tractor time required was influenced by such factors as the skill of the operator, implements used, length of run, and turning time. It was observed that the tractor required more turning time than a WTC. In straight runs, the advantage that could have been obtained in the tractor treatment was lost partly because of the requirement to operate slowly to avoid damage to the implements, which were designed for use with a WTC, and partly because of the small plot size.

Table 2 gives the range and average figures for pull force (draft) measured by a dynamometer placed in the beams of the WTCs. The data showed that it is the type of operation and not the type of WTC that determines the pull requirement, because over 90% of the pull is attributed to the implement used. Plowing and ridging are heavy operations. Regardless of pull in the range of 1600-2250 N (163-230 kgf), oxen were able to perform these operations and work continuously for 6 hours a day with normal rest periods. Similarly, the effect of the machinery system was not found to be significant on plant population and yield of sorghum and pigeonpea crops (Table 3). Further testing of the Tropicultor, Akola Cart, and Agribar revealed poor viability and transferability of the Akola Cart design. Inappropriate dimensional control and seasonal swelling and shrinking of the wooden components called for too much attention every year. As a result of this, no further design work with the Akola Cart was done.

Table 1. Average machine-hours per ha required for various operations with different machinery systems used in an Alfisol watershed, ICRISAT Center, 1979-80.

	Machinery systems			
	Animal-drawn WTC			
Operations	Akola Cart	Agribar	Tropicultor	Tractor
Plowing I	1.8	1.8	1.8	3.2
Cultivation	2.7	2.8	2.6	3.0
Plowing II	3.2	3.6	NR	NR
Ridging	3.2	3.6	2.7	3.4
Bed-shaping	3.4	3.4	2.4	2.6
Fertilizer application	3.3	3.2	3.0	2.7
Planting	1.9	2.7	2.0	2.8
Interrow cultivation I	3.1	2.7	2.5	3.0
Interrow cultivation II	3.7	3.7	2.9	3.0
Total	26.3	27.5	19.9	23.7

NR = Not required.

Table 2. Average and range of pu[illegible] observed for various operations with different machinery systems in an Alfisol watershed, ICRISAT Center, 1979-80.

	Machinery system					
	Akola Cart		Agribar		Tropicultor	
Operation	Range	Average	Range	Average	Range	Average
Plowing	1600-2250	2000	1700-2000	1950	1800-2000	1900
Cultivation	1500-1650	1550	1300-2000	1600	1400-1700	1550
Ridging	1750-1850	1800	1700-1800	1750	1700-1800	1750
Bed-shaping	1250-1600	1500	1200-1600	1450	1450-1550	1500
Fertilizer application	1100-1400	1300	1400-1600	1500	1400-1450	1450
Planting	1150-1200	1150	1100-1250	1200	1350-1400	1400
Interrow cultivation I	1300-1400	1350	1400-1500	1450	1400-1700	1600
Interrow cultivation II	1350-1650	1450	1050-1600	1350	1150-1600	1400

Table 3. Plant stand and grain yield obtained using different machinery systems in an Alfisol watershed, ICRISAT Center, 1979-80.

		Machinery system				
		Animal-drawn WTC				
Crop	Factor	Akola Cart	Agribar	Tropicultor	Tractor	SE (±)
Sorghum	Plant stand ha⁻¹	168000	185000	155000	166000	10760
	Yield (t ha⁻¹)	4.0	3.5	3.4	3.6	0.49
Pigeonpea	Plant stand ha⁻¹	68000	62000	69000	67000	4733
	Yield (t ha⁻¹)	0.44	0.45	0.45	0.44	0.065

Sowing and fertilizer application

Traditionally, sowing in India is done by the hand-metering of seed into a furrow opened by a country plow. A multirow wooden seed drill, called a "gorru" or "tippen", is also widely used for sowing. The use of inorganic fertilizer is relatively new among dryland farmers in India, and the sowing techniques they currently use are inadequate to meet the operational requirements if fertilizer is to be drilled at the same time as seed. Some multirow hand-metering seed drills have been modified for placing a basal dose of fertilizer along with the seed, e.g., the Royal gorru and Eenati gorru (Venkata Nadachary and Kidd 1981).

The traditional systems have several limitations that result in poor plant stands, even though the normal rate of seed application is 3 or 4 times more than that recommended (Soman et al. 1981). Traditional systems give uneven distribution of seed, which means crowding of plants at different locations in the same row and gaps elsewhere. Another limitation of this system is inappropriate placement of the seed, and delay in covering it. In Alfisols, with low soil-moisture retention capacities, any delay between opening and closing a furrow can adversely affect germination and emergence. Finally, ground coverage is slow, and traditional operations require at least two or three people. Thus, for completion of sowing of crops early in the rainy season, traditional sowing equipment is not adequate.

For moisture conservation in Alfisols, minimum soil disturbance, quick furrow closing, and proper compaction are essential for seeding. When more than 10 kg ha⁻¹ of nitrogen fertilizer needs to be applied at seeding, it should be placed in a band away from the seed to avoid salt injury (Sanghi et al. 1982). The separation of seed and fertilizer appears to be more important in Alfisols and related soils than in clayey soils such as Vertisols, probably because of lower availability of moisture around germinating seeds in the former case.

During the early phase of farming systems research at ICRISAT Center, fertilizer application preceded sowing as a separate operation in both Alfisols and Vertisols. A narrow shoe-furrow opener (Fig. 3a) was developed for planting on the lines where fertilizer was already banded. With the devel-

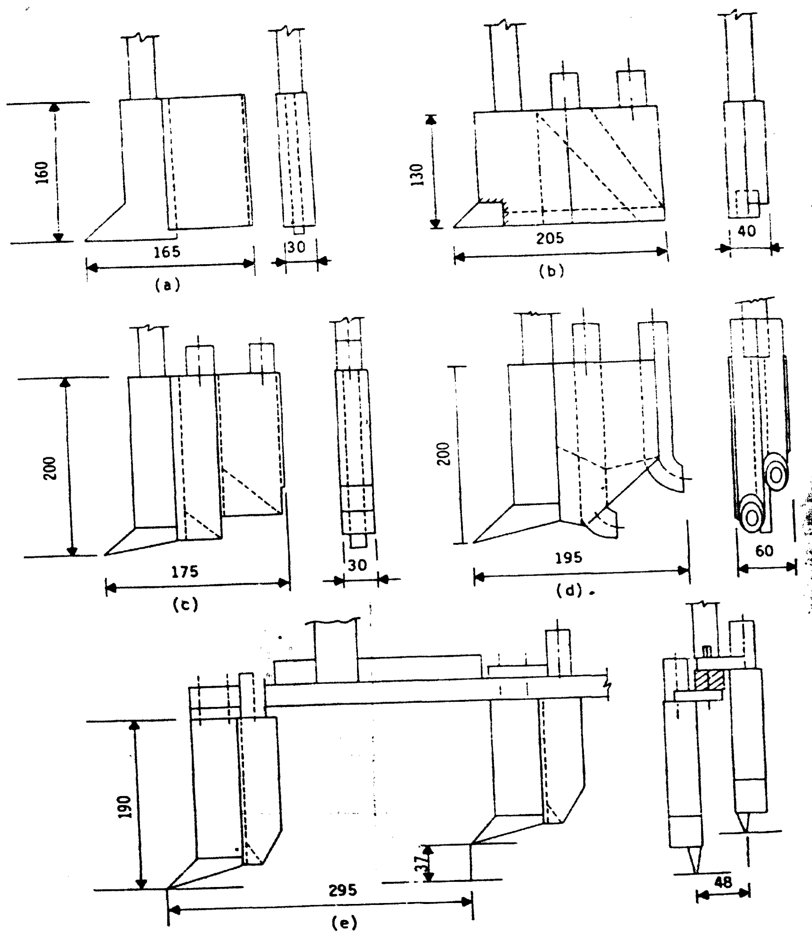

Figure 3. Furrow openers. (Measurements in mm.)

opment of a combined planter-and-fertilizer applicator a change in the furrow-opener design became necessary.

Figure 3b shows a two-chamber single-shoe furrow opener designed to cut a narrow slit for minimizing draft and soil disturbance. With this furrow opener, fertilizer was placed on one side of the seed and at the same level. Two main shortcomings of this design were found to be inadequate separation of seed and fertilizer, and clogging of the furrow opener with soil when lowered into the working position.

Another design (Fig. 3c) attempted to overcome these problems. It required fertilizer to be placed about 40 mm directly below the seed row. The furrow opener was closed at the bottom and had exits for seed and fertilizer at the rear. While this design got over the problem of clogging, seed and fertilizer separation varied from 0 to 20 mm owing to the poor flow of moist soil.

In the third modification (Fig. 3d), the furrow opener was made wide and had exits at different levels. Fertilizer was expected to fall in a band about 40 mm below and 30 mm to the side of the seed row, separated by a layer of soil. The performance of this design was also unsatisfactory because of insufficient seed and fertilizer separation. The seed tended to roll down on to the fertilizer band because the soil layer between them was thin. Covering a 60-mm wide furrow was also found to be a problem.

Finally, a double-shoe furrow opener (Fig. 3e) that keeps seed and fertilizer well separated was developed. It has two identical, narrow shoes bolted to an inverted T-frame that permits fertilizer to be placed 40-50 mm to the side and below the seed. Furrows opened by the fertilizer shoe are partially closed by the seed shoe. The seed row is covered and compacted by floating arms and a press wheel. The double-shoe furrow opener design gave adequate separation between seed and fertilizer, and performed without any problem of blockage in both Vertisols and Alfisols (ICRISAT 1984).

A four-row planter-and-fertilizer applicator developed at ICRISAT Center permits seed and fertilizer to be metered mechanically and to be placed at required depth. This planter is suitable for a wide range of crops grown in the SAT. Seed is metered by an inclined-plate mechanism. Metering plates, made in aluminium, can be changed easily to suit a particular crop. The fertilizer application rate is controlled by an oscillatory mechanism fitted to the bottom of the hopper. Both mechanisms are driven from the left wheel of the Tropicultor on which the planter is mounted. Test results from an ICRISAT Alfisol watershed showed that the machine can cover 1 ha in 4-5 hours depending on plot size, shape, and other operational factors (Table 4). Pull forces required for sowing on Vertisols and Alfisols are given in Table 5. Sowing of four rows of any crop on Alfisols was never found to be difficult because the pull requirement was not excessive and the oxen could sustain the load for normal working hours.

Development of a rolling soil-crust breaker

Soil crusts on Alfisols impede seedling emergence. Once a crust forms over a seeded row, it needs to be

Table 4. Actual field capacity for planting and fertilizer application in different land-management practices on Alfisols, ICRISAT Center, 1980-81.

Watershed no.	Land treatment	Crop	Actual field capacity, (ha h⁻¹)
RW-3D	BBF	Sorghum/pigeonpea	0.25
RW-3D	BBF	Pearl millet/pigeonpea	0.21
RW-3D	BBF	Castor/green gram	0.26
RW-3D	Flat	Sorghum/pigeonpea	0.21
RW-3D	Flat	Pearl millet/pigeonpea	0.20
RW-3D	Flat	Castor/green gram	0.26
		Average	0.22

BBF = Broadbeds and furrows.

Table 5. Pull requirement for planting and fertilizer application.

Soil	Crop	No. of rows per pass	Pull (N)		CV (%)	SE (±)
			Range	Mean		
Vertisol	Maize	2	900-1400	1080	11	24
Vertisol	Sorghum/pigeonpea	3	1400-1700	1470	6	18
Alfisol	Pearl millet	3	1000-1400	1240	13	33
Alfisol	Cowpea	4	1300-1700	1530	8	25

wetted frequently or broken mechanically for satisfactory seedling emergence.

During rainless periods, application of water in the SAT is impractical, however, because of its limited availability; labor requirements and equipment cost are the other constraints. Farmers have no traditional equipment for breaking soil crusts. Therefore, a rolling crust breaker was developed that can be used on seeded rows (Awadhwal and Thierstein 1983). The manually-operated rolling crust breaker (Fig. 4), which can also be attached to a WTC, has two 150-mm diameter rollers with 16 rows of spikes 25 mm long. Spacing between the rows and the length of spike were selected to ensure that no crust was left undisturbed. The crust breaker covers a 180-mm wide strip over the seed row.

Performance of the rolling crust breaker was evaluated on Alfisol fields with sandy, sandy loam, and

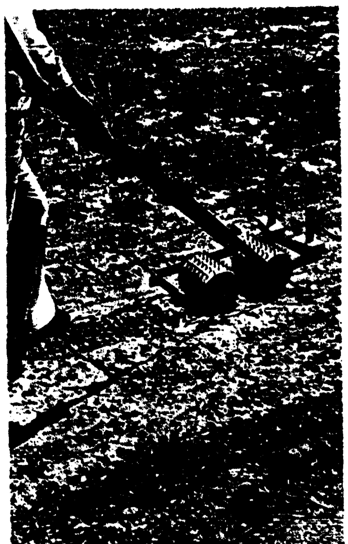

Figure 4. A manually-operated rolling soil-crust breaker.

sandy clay soils. We examined the effect of breaking surface crusts on different pearl millet and sorghum genotypes. The pearl millet and sorghum genotypes were planted manually; about 35 mm of water was applied, by sprinkler from a height of 2 m, to produce a reasonably uniform and hard crust. A day before expected emergence, the crust surface was dry and its strength, measured with a pocket penetrometer, was in the range of 196 to 245 kPa (2.0 to 2.5 kg cm^{-2}).

The rolling crust breaker was used to break the soil crust on the seeded rows 1 day prior to the day of expected emergence. The emergence count was taken 1 week after the breaking of the crust. Seedling emergence under crusted conditions was very poor, and the use of the crust breaker increased the emergence significantly when soil moisture was not a limiting factor (Awadhwal and Thierstein 1983).

Tillage Studies on Alfisols

Tillage experiments were conducted on Alfisols for 4 years from 1978 (Klaij 1983, Awadhwal and Thierstein 1984). The objectives of the studies were to evaluate alternative primary tillage practices and their effect on crop production, in terms of soil reaction to tillage tools, plant and soil interaction during plant establishment and early growth, and to evaluate seedbed requirements.

Tillage operations consume a large proportion of the total energy expenditure in all field operations. Hence the study also aimed to provide an understanding of the factors that can lead to the saving of energy. The experiments were conducted on a broadbed-and-furrow configuration where the traffic zone (furrow) is clearly separated from the cropping zone (broadbed). Four primary-tillage treatments evaluated, shown in Figure 5, were split-strip tillage covering the entire width of the broadbed in three successive passes of the WTC; strip plowing with right- and left-hand moldboard plows; chiseling to 120 mm depth at locations where crop rows were to follow; and shallow cultivation by duckfoot sweeps. The treatments were performed by using respective implements in conjuction with a WTC.

Variation in the rainfall pattern from one year to another, which affected moisture availability, had a greater effect on crop growth than the intensity of primary tillage. Intensive tillage by the split-strip method tended to make better seedbeds by turning and mixing the soil across the entire width of the broadbed, thus covering weeds properly. When compared with other treatments, weed intensity in split-strip tillage plots was less up to 22 days after planting, even though data were significant only at the 10% probability level (Klaij 1983). Tillage treatment did not affect weed development late in the season.

The major effect of tillage treatments was expected to be on availability of soil moisture during crop growth. Table 6 shows trends of soil moisture

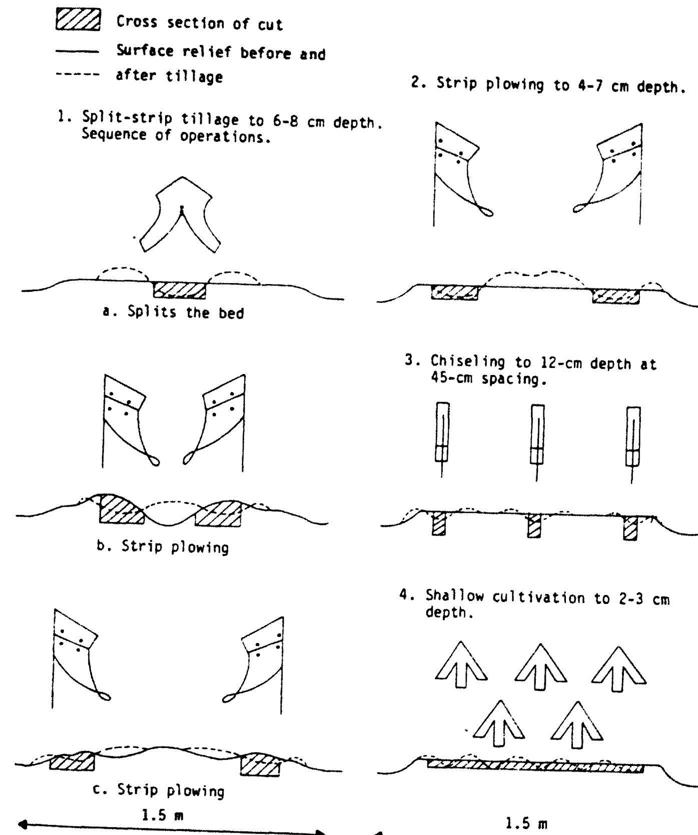

Figure 5. Four primary tillage methods for a broadbed-and-furrow system on Alfisols.

Table 6. Effect of tillage methods on soil moisture on an Alfisol during no-rain periods, ICRISAT Center, rainy season 1981.

No. of dry days	Tillage methods: Split-strip plowing	Strip plowing	Chiseling	Shallow cultivation	Mean	SE (±)
	Soil moisture (mm) in top 20-cm layer					
0	45	43	44	43	44	0.6
2	31	29	34	35	32	0.7
4	28	29	30	33	30	0.5
9	22	25	28	32	27	0.5

Source: Awadhwal and Thierstein 1984

depletion in the top 20-cm layer during the early growth of the sorghum crop. Split-strip tillage holds marginally more of water, but moisture depletion during stress is faster. Consequently, at the end of dry spells moisture in intensive tillage is less than in shallow-tillage treatments.

There can be two hypotheses to explain differences in soil moisture in different tillage plots. First, the intensive-tillage treatment provided a better environment for plant growth and root development resulting in higher rates of transpiration that led to faster depletion of soil moisture. Secondly, in shallow tillage the soil is stratified in two layers: a top-tilled layer and a subsurface-untilled layer. This stratification caused discontinuity of pores, resulting in increased resistance to moisture migration. In the case of the moldboard-plowed soil the entire plowed zone was in one layer with better continuity of pores, which, coupled with higher porosity, enhanced moisture loss through evaporation. These hypotheses require validation by further research (Awadhwal and Thierstein 1984).

Effect of tillage treatments on crop yield was not consistent (Table 7) and thus there is no conclusive evidence to suggest that any one treatment was better. However, split-strip tillage gave significantly (P <0.05) more yield (2460 kg ha^{-1}) in a year of low rainfall (1979) than in field RA-14 which contains a fair proportion of gravel in the top layer (1120 kg ha^{-1}). Apparently soil moisture was greater only in RA-14 where the crop responded well to the increased tillage because of enhanced infiltration. In the following year the same field gave much lower yields across all treatments. Sorghum grain yield varied considerably from year to year in RW-2B, where the clay content was greater. The results did not have significant differences.

Energy expenditure in primary tillage was esti-

Table 7. Effect of primary tillage on sorghum grain yiel (kg ha^{-1}) in Alfisol fields, ICRISAT Center, 1979-81.

Treatment	Field identification and year: RA-14 1979	RA-14 1980	RW-2B 1979	RW-2B 1980	RW-2B 198
Split-strip plowing	2460	1130	2970	1800	308
Strip plowing	2140	1120	3080	1750	301
Chiseling	1970	910	2870	1450	268
Shallow cultivation	1950	1060	3040	1910	287
Mean	2130	1050	2990	1740	291
SE(±)	90	116	111	120	26

Source: Klaij 1983; Awadhwal and Thierstein 1984.

mated by measuring the draft and the travel distanc required to cover 1 hectare. As expected split-stri plowing consumed a much higher level of energ (28.2 MJ ha^{-1}) as compared with strip plowing (1 MJ ha^{-1}), chiseling (9.6 MJ ha^{-1}), and shallow culti vation (7.7 MJ ha^{-1}). Part of the excessive amount c energy used in the first case could be compensate for by saving one secondary tillage operation fo seedbed preparation, which was otherwise necessar for effective weed control.

Conclusions

Improved, ox-drawn wheeled tool carriers an implements developed so far have shown conside able advantages in terms of the timeliness and qua ity of operations. The highest draft requirement w recorded for plowing with a set of left- and righ hand moldboard plows operating on a broadbed i the range of 1600 to 2250 N, with an average of 20

N. For a single right-hand moldbo... plow operation on flat land the draft values were in the range of 1180-1670 N, with an average of 1470 N. For other operations the draft values recorded were far less. An average pair of oxen was able to sustain these loads for a usual working period in a day. For sowing all common crops in Alfisols and Vertisols a planter-and-fertilizer applicator gave good results. It could sow sole crops as well as intercrops, and place seed and fertilizer with required precision. All these machines were drawn by a pair of oxen of average size.

A crust breaker, used either as an attachment to a WTC or as a hand-pushed implement, facilitated the emergence of seedlings and improved the stands of sorghum and pearl millet in fields where a surface crust was formed by natural drying processes. Primary tillage studies on Alfisols conducted for 4 years revealed that intensive tillage improved the pore-space and water-retention capacities of these soils, and reduced weed infestation in the early stages of crop growth. It also enhanced the risk of soil erosion in the absence of adequate crop cover. Advantages accruing from intensive tillage can therefore be realized only in conjunction with soil-conservation practices. In the years of normal and better-than-average rainfall, shallow tillage treatments gave comparable yields. It is thus clear that defining the best tillage techniques for Alfisols is a subject for further studies.

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