likely to be adopted and maintained for soil and water conservation. When parallel terraces are not possible, odd-shaper3 areas that cannot be easily farmed can be planted to grasses or legumes to provide feed for livestock; they can also be used for fruit and vegetable crops. Such use, however, would depend on the size of area involved, needs of the farmer, suitable markets for the products, and other factors.

5.7 DIVERSION TERRACES, WATERWAYS AND GULLY CONTROL

Two special requirements must be met when terraces are used to control erosion. First, water from upslope areas must be kept off the field and, second, water flowing from the terraces must be conveyed non-erosively from the land to suitable streams. Water from upslope areas can be kept off the field by diverting the water with diversion terraces. These are individually designed structures (channels and ridges) across a hillside to convey runoff water to a point where it will not affect the terrace system. Other uses for diversion terraces are to protect unterraced areas, divert water out of active gullies, protect farm buildings from runoff, reduce the number of waterways, and shorten the length of slope so that erosion control by strip cropping becomes more effective (SCSA 1982).

Water from graded terraces, level terraces with open ends, or level terraces with closed ends that overflow or require draining must be conveyed off the land in a non-erosive manner for overall soil conservation. On gentle slopes, water can usually be safely discharged onto adjacent grassy or wooded areas, if available; but if these are not available, then waterways are required. Waterways may be natural or specially constructed, are usually broad and shallow, and should be covered with locally-adapted, erosion-resistant grasses (Gil 1979; SCSA 1982). Grasses which form a sod, for example, Bermuda grass, are especially desirable for use in waterways. In semi-arid locations, special care must be taken to select and establish adaptable grasses which will protect the waterway from damage by erosion.

Vegetated waterways that are wide, shallow and crossable by machinery are effective for controlling erosion on slopes up to about 15 percent. On steeper slopes, vegetation will not supply the necessary protection. In such cases, vegetated waterways with drop structures of stone or other materials or waterways paved with stone are required (Gil 1979).

Drop structures in waterways are extensions of the retaining wall or ridge of terraces. Their height is less than that of the wall or ridge and is determined by the anticipated flow in the waterway. Where terraces are widely spaced, additional drops may be required. The waterway itself is protected against erosion by perennial grasses (Gil 1979).

On very steep slopes, grasses are not always practical, and the waterways are often paved with stone. Although costly, this method has the advantage that the waterway can 5e used as a path to the field. Since other access would have to be provided at additional cost, combining the waterway and path reduced overall costs and also adequately serves both purposes (Gil 1979).

Several methods are available to control erosion in gullies. Erosion in small gullies can usually be controlled by using good conservation farming practices which control the rate and amount of runoff water leaving the field and the point where the water is discharged (such as into a properly designed waterway). Where a large gully exists, a diversion terrace may be required to keep runoff from entering the gully. Once the water flow is controlled, then grass, drop structures, or permanent control structures can be used to stabilize the gully to prevent further erosion (Figs. 99, 100) If the gully is to become a part of the overall conservation system

Fig. 99 Bunch-type grasses help stabilize gullies, but are less effective than sod-type grasses (FAO photo)

Fig. 100 Check dams in gully. Silt settles behind the dams, thus filling the gully, enabling terrace construction and rehabilitation of a critically eroded area in the Upper Solo Valley, Indonesia (WFP photo, issued by FAO)

on the watershed, then gully shaping and grass establishment may be required to prepare it for use as a waterway (Constanti nesco 1976) .

A special deterrent to the use of terraces and associated structures (diversions and waterways) for water and soil conservation is the limited size of farms in many countries. Whereas land smoothing, contouring, strip cropping, etc. are adaptable to almost any sized area, terraces should cover major portions of the entire watershed to be most effective. Where farms are small, this requires that several farms be covered by one system. Unless farmers recognize the need for conservation and share the benefits from installation of the systems, they may be reluctant to participate in a programme which seemingly adversely affects their own farms.

5.8 LAND LEVELLING

Land levelling has been covered in part in Section 5.6 in relation to the CBT and bench terrace systems. By levelling the land (Figs. 101, 102), water from precipitation is more uniformly stored in soil, erosion is minimized and crop production is more uniform on the entire field.

Land levelling is also important for uniform distribution and conservation of irrigation water and water obtained from specially-treated areas and intermittent streams during periods of runoff. The areas levelled may be entire .fields, basins bounded by small dikes in a field (Figs. 101, 102), basins in adjacent to natural waterways, and specially developed catchment areas that receive water from particularly treated water harvesting areas. Special structures may be required to convey water to the field and distribute it without causing erosion. Appropriate conveyance methods, such as lined ditches or pipes, also decrease water losses due to deep percolation, seepage or use by non-crop plants (Figs. 103, 104).

5.9 WATER HARVESTING, RUNOFF FARMING AND WATER SPREADING

Water harvesting involves treating watersheds to enhance runoff and its collection to increase crop yields on limited areas (Section 5.7) or for use by livestock. Nearly all rainfall can be collected as runoff when soils are covered with asphalt emulsions, aluminium foil, butyl rubber or plastic film. However, such materials are expensive and easily damaged by livestock and wild animals. Less rainfall was captured as runoff when land was smoothed, rocks were removed and soil was sprayed with water repellents (Bertrand 1966). However, use of waxes, which are by-products of the petroleum industry, has shown promise to improve water harvesting in recent years (Fink 1982).

Water harvesting on a small scale was achieved at Mandan, North Dakota (USA), by covering ridges between 1 m spaced rows of maize with black plastic film. Runoff from the field was prevented. Maize yields averaged 4 130 and 2 410 kg/ha with covered ridges and non-treated areas, respectively (Willis 1962; Willis et al. 1963). The yield increase with covered ridges was attributed to better utilization of light rainfall, lower evaporation and higher soil temperatures in the spring.

Mickelson (1966) and Mickelson et al. (1965) constructed level basins in or adjacent to natural waterways at Akron, Colorado (USA), to intercept runoff from the waterways. Watershed to basin ratios ranged from 3:1 to 56:1. Runoff flowed into the uppermost basin until it reached a predetermined level, then flowed through or by-passed that basin to fill the next basin at a lower elevation. At sorghum planting from 1962 to 1964, available soil water contents averaged 10.2, l83.9 and 19.7 cm no continuously cropped (non-level), after fallow (non-level), and continuously cropped (level basin) areas, respectively. 5orghum yields on the respective

Fig. 101 Levelling land with laser-controlled scraper (photo provided by O.R. Jones, USDA-ARS)

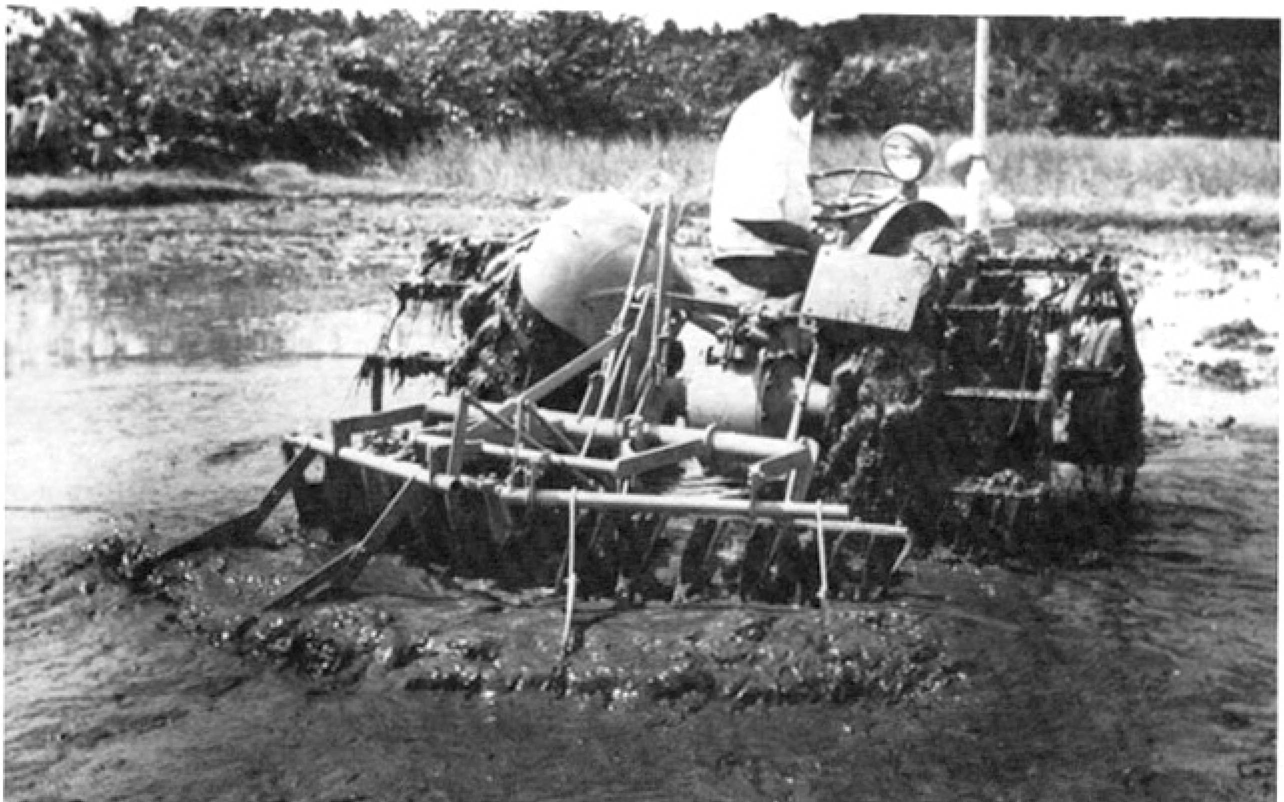

Fig. 102 Levelling land for rice production (FAO photo)

Fig. 103

Use of concrete conduits in Jordan eliminates water losses due to seepage and use by phreatophytes (FAO photo)

Fig. 104

Water rising from underground pipeline. Use of pipes reduces water losses (FAO photo)

areas averaged 350, 1 320 and 3 030 kg/ha. The major yield increase with level basins, compared with that no fallowed areas, resulted from runoff collected during the growing season, because soil water contents for these treatments were similar at planting time.

The practice of collecting runoff for crop production is an nld one, having been used for agricultural projects in the Negev Highland desert in Israel between 950 and 700 BC. Although the region receives an average of only about 100 mm of rainfall per year, concentrating runoff from surrounding watersheds permitted Evenari (1968) to grow orchard, pasture and field crops after reconstructing the collecting conduits, distribution ditches and pipes, and field areas. A system of microwatersheds that provided runoff for use by individual plants was also established. The collected water improved growth and yields of the various crops evaluated (Cohen et al. 1968; Evenari et al. 1968; Shanan et al. 1970; Tadmor et al. 1970). In the study with range plants, optimum yields were obtained with 32 m microwatersheds (Shanan et al. 1970).

A unique form of water harvesting is the capture of fog to supply water for plants or for human and animal use. The people in a small settlement on the Huri Hills in Kenya, for example, collect between 18 and 26 litres of water per day from the drippings of a large tree. In experiments in Kenya on Mount Marsabit, at an elevation of about 1 400 m, up to 6 litres of water have been collected from the air in 4 hours by using a 0.9 x 1.8 m (3 x 6 ft) vertically positioned 0.64 cm (0.25 inch) mesh screen (Seitz 1977). Such an amount of water, although relatively small, could provide sufficient water to establish trees (Seitz 1977) or produce food crops on small plots.

Water spreading is the practice of diverting runoff water from gullies or streams for spreading over relatively flat areas, mainly on range or pasture land. The water is diverted by a system of dams, dikes, or ditches (SCSA 1982). The additional water usually increases production on the flooded area at times when that on other areas may be low. The additional forage may extend the grazing season and thus increase overall livestock production. Water use efficiency with water spreading is low. However, if the water would otherwise be lost, this system may be economically advantageous if it is simple and can be constructed cheaply (Hudson N. 1981).

The foregoing systems of capturing water for crop production relied on storing the water in soil for subsequent use by plants. Another technique is to store the water in ponds during runoff periods, then use it to irrigate crops during water deficient periods. Major irrigation projects often involve water storage behind large dams. Such systems are highly complex, require intensive planning and major construction and expenses (Gil 1979); they are beyond the scope of this report. However, similar systems on a smaller scale for on-farm storage of water can lead to positive results. By storing water in ponds during rainy periods, crop production can be stabilized or improved by irrigating during a dry period within the rainy season or by extending crop production into the normal dry season (Charreau 1977; Gil 1979; Krantz et al. 1978; Sanchez 1977; Singh 1974). Some factors to consider regarding ponds include site selection, watershed size and condition, rainfall distribution and runoff, and water requirements of crops to be irrigated. The pond may also be used to store water for livestock and, if a minimum water depth of about 1 metre can be maintained, fish can be raised which could provide food for the farmer (Gil 1979).

5.10 MICROWATERSHEDS AND VERTICAL MULCHES

Microwatersheds and vertical mulches are often used in a combination system. However, each serves a distinct purpose. Microwatersheds enhance runoff from part of a field and concentrate the water on a relatively small area for crop use or storage in the soil. Vertical mulchs, by providing a residue-filled slot open to the surface at the site of water concentration, result in rapid channelling of water into the soil.

Vertical mulches where the surface was level saved 30-40 percent more water than did a furrow treatment under laboratory conditions. Wetting the entire surface during water application decreased water storage by 17 percent with vertical mulching. When a microwatershed was added, 7-10 percent more of the water was stored with a vertical mulch than without. Depth of water penetration and amount of dry surface soil adjacent to the mulch were factors that affected evaporation from vertically mulched soil (Fairbourn and Gardner 1972).

A vertical mulch resulted in saving 16 percent more water than a nonmulched microwatershed and 41 percent more water than a control treatment (no watershed or mulch) under field conditions at Akron, Colorado (USA). Check dams across the surface were an important feature of the microwatershed system. With the vertical mulch treatment, sorghum grain yields were from 37-150 percent higher than with the control treatment (Fairbourn and Gardner 1974).

As expected, a vertical mulch on Olton clay loam at Lubbock, Texas (USA), did not affect soil water contents and yields in a year (1970) without runoff. However, in 1971, runoff increased water contents at the 30-90 cm soil depth in vertically mulched plots. The water contents remained higher throughout the growing season of sorghum, which yielded 2090, 2490 and 3110 kg/ha of grain on control, vertical mulch and vertical mulch with oil (sprayed on soil between rows) plots, respectively. The differences were statistically significant (Wendt 1973a). A vertical mulch had little effect on water infiltration and crop yields on Pullman clay loam at Bushland, Texas (USA), when the land was disked after installing the mulch (Hauser and Taylor (1964). The mulch must extend to the surface to permit rapid water entry into the soil.

Trenching of Harlington clay in south Texas to 61 or 102 cm depths and backfilling the trenches with soil or vermiculite increased water infiltration rates, decreased soil bulk density in the trenches, increased rooting depth of cotton and decreased soil salinity. Cotton lint yields were significantly increased by trenching in 2 out of 3 years, with the 61 cm deep trench filled with vermiculite resulting in the highest average yield (Heilman and Gonzales 1973).

5.11 MULCHING

Crop residues, which are a type of mulch, have been mentioned repeatedly in foregoing sections with respect to their value for controlling wind and water erosion, and for conserving water. However, many other materials have been used as mulches. Ancient Romans placed stones and Chinese placed pebbles from streams on soil to conserve water (Jacks et al. 1955). Such practices may be practical where labour is abundant, but not for modern, large-scale, mechanized agriculture. However, some artificial mulches, besides the crop residues mentioned in other sections, may be practical for some high value crops. Materials used for mulching have included plastic films, paper, crude oil, gravel, bitumen, coal, etc. (Fairbourn 1973, 1974; Fairbourn and Kemper 1970; Jacks et al. 1955; Unger 1971a, 1971b, 1975b; Wendt 1973b, 1973c; Wendt and Runkles 1969). The mulches usually increased soil water contents through improved infiltration and/or decreased evaporation. Consequently, crop yields were usually also increased.

5.12 COVER CROPS AND CATCH CROPS

Cover crops are close-growing crops such as grasses, legumes or small grains (Fig. 105). These crops are grown primarily for seasonal protection against erosion and for soil improvement, and usually remain on the land for less than one year (Soil Conservation Service 1977). Major disadvantages of cover crops in dryland farming areas are the difficulties in establishing the crops because of limited water supplies and, once established, the use of water that could subsequently be used by another crop.

Fig. 105 Bromegrass, which will serve as a cover crop to protect the land against erosion, was seeded in maize after the last cultivation (USDA-Soil Conservation Service photo, issued by FAO)

A catcn crop is a crop that is grown to replace a main crop that has failed (SCSA 1982). The crop may have failed because of too little or too much rainfall at the time for planting, so crop not planted; destruction by hail, excessive rainfall, insects, diseases, etc.; or failure due to drought. Catch crops have different growing seasons or other requirements to the main crop, and are therefore established when conditions become favourable. Use of catch crops provides some food or income for the producer, permits use of water that otherwise might be lost, and may provide a growing crop or crop residues during a critical period for erosion.

5.13 LAND IMPRINTING

Land imprinting (Dixon 1981a, b, c) is the practice of using a massive steel roller faced with two patterns of angular steel teefh to form relatively stable impressions (imprints) on the soil surface (Fig. 106). The imprinter is pulled by a tractor and seed, which is normally spread ahead of the imprinter, is pressed into the soil by the imprinter.


Fig. 106 Land imprinter (photo provided by R.M. Dixon (USDA-ARS)

The imprinting system was developed to improve vegetation on overgrazed and shrub-infested arid to semi-arid rangelands while protecting land against accelerated runoff and erosion. When operated on the contour, the imprinter forms a system of interconnected watershedding and water-absorbing furrows which constitute a miniature rainfed irrigation system. The sharp angular imprinting teeth crush and cut above ground plant materials, partially imbed them in soil, and deposit the remainder as a mulch on the soil surface.

The action of raindrops and runoff move seed, topsoil and plant litter into the furrows where they are concentrated along with the water to enhance the probability of successful germination and seedling establishment. The latter is further enhanced by the surface mulch which also protects the surface against sealing, thus permitting rapid and deep penetration of water into the soil, and which minimizes soil water evaporation (Dixon 1981a, b, c).

Although designed primarily to improve rangelands (Dixon 1981a), the imprinting system also has potential for soil and water conservation on cropland, especially on land covered with residues from a previous crop and which is to be cropped to small grains in semi-arid regions.

The land imprinting system per se is simple and capable of contin uous operation on rough and even rocky land. However, the underlying principles are complex and represent edaphic, agronomic, ecologic, and hydrlogic sciences and technologies. The prime requisite for successful vegetation establishment is adequate precipitation. To enhance the probability of successful establishment, imprinting should be timed with respect to anticipated rainfall. In addition, high-quality seed of suitable species or mixtures or species should be used at rates suitable for the conditions under which the plants are to be grown (Dixon 1981a).

5.14 IRRIGATION

Irrigation is highly important for crop production in many parts of the world, and the science and technology of irrigation is thoroughly covered in numerous publications. Therefore, irrigation is treated only briefly in this report, and mainly with respect to water conservation and its effect on erosion.

Opportunities for conserving irrigation water exist from the storage reservoir to the point of use by plants. However, only on-farm possibilities are considered in this report. Losses of irrigation water on the farm may result from poor conveyance systems, land preparation, application techniques and cultural practices. The greatest losses from conveyance systems result from seepage from unlined ditches or canals (Fig. 107). Substantial losses may also occur due to water being used by phreatophytes, with relatively minor losses resulting from evaporation from the free water surface. Water losses from conveyance systems can virtually be eliminated by using lined ditches or canals (Fig. 103) or, better still, by using underground pipes for main conveyance lines (Fig. 104), then surface pipes to the point of application to land.

Fig. 107 Workers irrigating cropland in Costa Rica. Using unlined ditches increases water losses from seepage and use by phreatophytes (UN photo, issued by FAO)

Poor land preparation may cause substantial losses or inefficient use of irrigation water. Land preparation will differ depending on the irrigation system used. Where water flows across the surface for distribution (furrow, basin or flooding irrigation), land should have a uniform shape or be level so that all areas receive the same application of water. Land smoothing or levelling is usually required for uniform distribution of irrigation water (Figs. 101, 102). When water is applied through a drip or sprinkler system, land preparation is less critical. However, noticeable irregularities in the land surface still cause uneven retention of water in soil, especially with sprinklers. Where this is the case, greater uniformity can be achieved by basin listing the land to be sprinkler irrigated (Fig. 94) (Aarstad and Miller 1973; Lyle 1979). Greater uniformity than with the control treatment was also achieved with a mulch on the soil surface (Aarstad and Miller 1973).

A well-designed irrigation system is based, among other factors, on soil water infiltration rates, water retention in soil and water availability. Consequently, to maximize the use efficiency of available water resources, water must be applied according to design criteria for the particular system being used. Regardless of application method (furrow, basin, flooding, sprinkler or drip), water is mainly lost either by deep percolation or runoff, or both. Poor distribution may result in low use efficiency.

Assuming adequate design of the systems, application techniques that result in low efficiencies and water losses are given on the left, with possible consequences on the right; they include:

i.	time of application too long	excessive deep percolation high amount of runoff
ii.	time of application too short	poor water distribution low amount of water storage in soil
iii.	rate of application too high	high amount of runoff low amount of water storage in soil
iv.	rate of application too low	poor water distribution excessive deep percolation at input site low amount of water storage at other sites
v.	water applied too frequently	excessive deep percolation high amount of runoff
vi.	water applied too infrequently	excessive infiltration poor water distribution.

The foregoing examples do not include losses due to evaporation and effects on crop growth and yields which are also affected by poor water application techniques.

Poor cultural practices affect irrigation water losses in the same manner as they affect water losses from precipitation. The major difference is that rate, amount and time of water application can be controlled with irrigation and, therefore, can be adjusted to the prevailing soil conditions resulting from cultural practices. However, practices to maintain adequate infiltration rates, reduce evaporation, control weeds, etc. are essential for efficient use of irrigation water.

As with precipitation, water erosion can be a serious problem with irrigation, especially when the land is poorly prepared and when the water application techniques are poor. The same factors that cause excessive water losses from runoff often also cause soil erosion, as discussed in previous sections. Although irrigation can cause erosion, it can also be managed to control erosion, both by water (from precipitation) and by wind. Control of water erosion can be achieved by irrigating to obtain timely and uniform crop establishment, thus resulting in a protective plant canopy or density at the time of greatest potential runoff and erosion. Irrigation can also be used on critical areas, such as on earthen dams, diversion terraces, steep backslope terraces, waterways, etc. to establish vegetation, which could be difficult to establish on a timely basis without irrigation, otherwise excessive erosion could occur during periods of precipitation and runoff.

In like manner to controlling water erosion, irrigation also has potential to control wind erosion by contributing to crop establishment, which could be delayed if it depended on rainfall. Control of wind erosion is further enhanced by providing the soil with water: so that it is less or non-erodible, so that tillage can be performed to create soil roughness or erosion-resistant soil ridges, and so that crops can be produced on areas which would otherwise be non-arable and highly susceptible to wind erosion.

5.15 DRAINAGE

The emphasis in foregoing sections of this report has been on soil and water conservation. However, periods of too much water can be as detrimental to crop production as too little water. Problems with excess water and poor drainage are usually most severe in high rainfall areas. However, these problems can also occur in drier regions.

The effects of excess water and poor drainage have been mentioned in a few cases. Where excess water and poor drainage are problems, water must be conveyed from land at non-erosive velocities to protect the land resources. Surface water is normally removed from land by terraces, waterways, canals, etc. by gravity flow. However, from some low-lying areas, water must be pumped across levees or dikes for final discharge from the area. Internal drainage from soils may be achieved by disrupting impervious layers in the soil, by canals, or by various types of subsurface drains which discharge into canals with final discharge by gravity flow by pumping across levees or dikes.

Drainage of excess surface water and internal soil water has been treated extensively in numerous publications, including monographs edited by Luthin (1957) and van Schilfgaarde (1974). Such publications should be consulted for detailed information on drainage systems.

Major drainage systems often involve large areas, frequently covering either a large farm or numerous smaller farms. Drainage on a small scale is also possible on small individual farms by using some basic principles of water flow and soil management. On land with a slight uniform slope, drainage can be improved by laying off crop rows in the direction of maximum slope, thus creating a natural drainage system toward the lowest point in the field where the water can be discharged into a natural or developed waterway, if available. If neither is available, the excess water would affect only a small area rather than the entire field, or it could be discharged into a pond from which the water could be subsequently used for irrigation during a dry period (Krantz et al. 1978). For fields with non-uniform slopes, the rows should drain into low areas or waterways within the field, thus improving overall drainage. For fields with unconnected low areas, drainage can be improved by connecting them with a series of ditches which eventually permit discharge into an established waterway, to the lowest point in the field, or into a pond.

For nearly level fields with relatively slow drainage, the drainage problem on a small scale can be partially overcome by developing a system of beds and furrows. For example, Krantz et al. (1978) obtained higher yields in India when crops were planted on raised beds or ridges than when flat planted (Tables 76 and 77). The beds, which were constructed with a slight gradient, provided more rapid drainage of the seed zone. Excess water was removed from the field by the accompanying furrows. However, because of the slightly sloping construction, the runoff was sufficiently slow to avoid erosion being a problem and infiltration was adequate to conserve water for later use by plants. Planting on raised beds was also recommended by Bradfield (1969) for intensive cropping where the period between rains was relatively short. Soil in beds dried more rapidly, which provided a better chance for planting before the next rain, than in areas without beds. In monsoon rainfall areas, as in other areas, timely planting is essential to maximize production where intensive cropping practices are used (Bradfield 1969).

Table 76   EFFECT OF LAND MANAGEMENT ON CROP YEILDS ON A DEEP VERTISOL (MEANS FOR 1976-77 AND 1977-78) (from Krantz et al. 1978)

Land treatment	Yield	
	Maize	Chickpea
	kg/ha	
Flat planting	2 690	650
Narrow (75 cm) ridge planting	2 790	590
Broad (150 cm) bed planting	2 800	830

Table 77   GRAIN YIELD AS AFFECTED BY PLANTING METHOD IN TWO CROPPING SYSTEMS ON DEEP VERTISOLS IN INDIA (1967-77) (from Krantz et al. 1978)

Planting method	Cropping system			
	Intercropped		Sequentially cropped	
	Maize	Pigeonpea	Maize	Chickpea
	kg/ha			
Bed planted	3 290	760	3 210	600
Flat planted	2 910	620	2 640	360

5.16   CONTROL OF DRIFTING SAND AND SAND DUNES

Sand drifting and dune formation and shifting could be avoided, in many instances, by using good water conservation and erosion control practices. However, even where such practices are used, sand drifts and sand dunes shift due to continued movement by wind (Figs. 14, 15, 108). Where such conditions adjoin cropland, crops may be damaged or destroyed or cropland may be covered, thus decreasing yields and the amount of land available for crop production.

The main requirement for controlling sand movement is to establish vegetative barriers. Where crop residues are not available, this may require partial land levelling, fertilization, mulching and planting of adapted grasses, shrubs and trees (Fig. 109). Such practices should be carried out when rains are adequate and wind speeds are lowest (Constantinesco 1976). Other means of minimizing sand movement are to erect barriers of dead shrubs, palm branches or corrugated asbestos-cement sheets, or to apply chemical emulsions (petroleum by-products, rubber emulsions, lignin materials) (Fig. 110) (ESA 1981[?]; Moomen and Barney 1981). Sand trapping materials must be replaced or raised as dunes become higher. This is labour intensive and requires a considerable amount of materials. When the areas become stabilized, drought-resistant species are planted (Bensalem 1977).

A unique approach to dune stabilization in Australia was reported by Downes (1970). Because dunes have rough, irregular shapes, they must be reshaped before alfalfa can be grown on them. This is usually accomplished by sowing a cereal rye crop around the base of the dunes, then letting the

Fig. 108 Dune encroachmant on cropland in Texas (USA) (photo provided by D.W. Fryrear, (USDA-ARS)

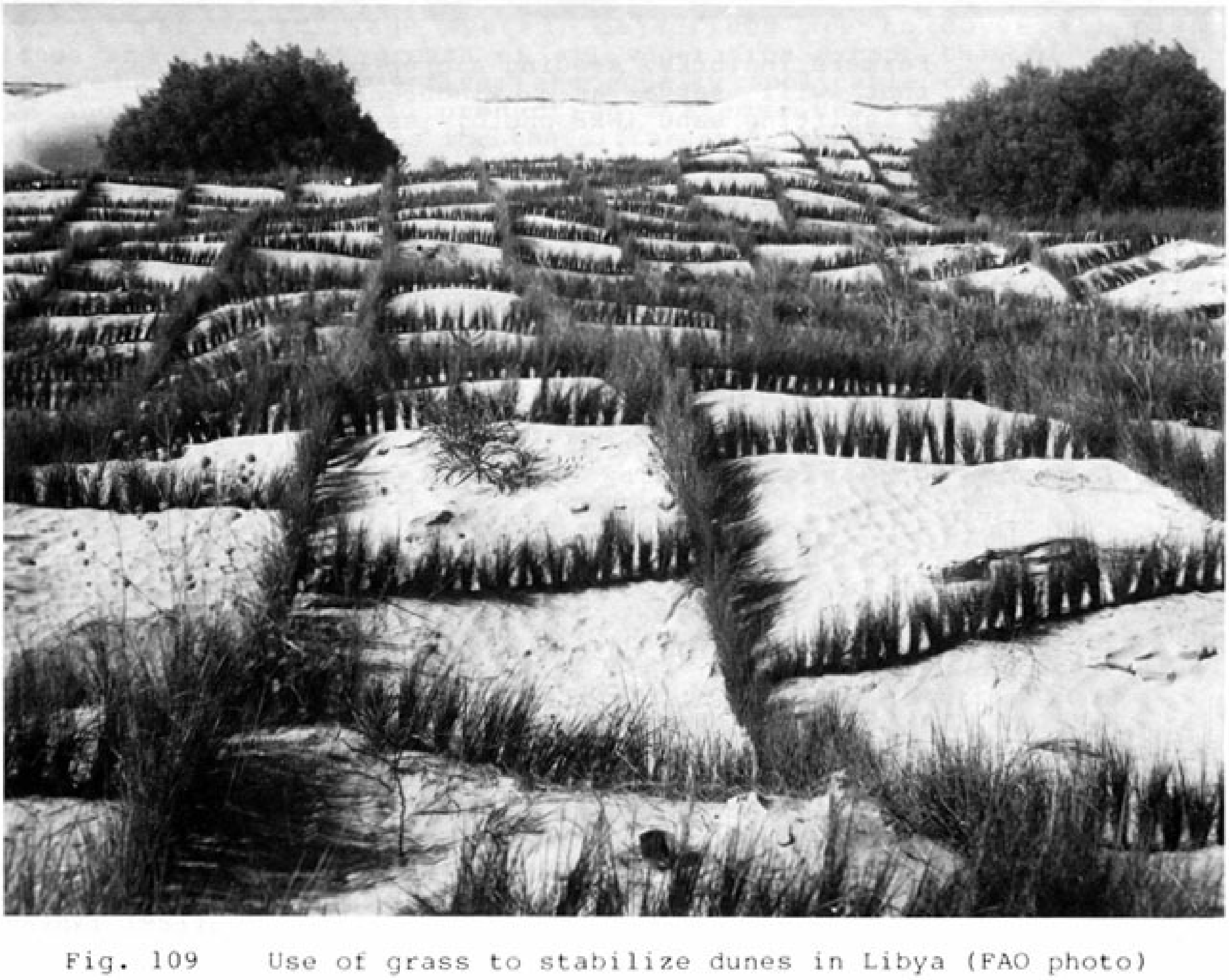

Fig. 109 Use of grass to stabilize dunes in Libya (FAO photo)

Fig. 110 Farmers in Turkey seeding a crop behind a fence that will serve as a windbreak and control shifting sand (WFP photo, issued by FAO)

rye trap sand as it blows off the dunes, which improves the shape of dunes. After several seasons, rye can be planted over the entire dune, and then alfalfa can also be established which provides permanent dune stability. Alfalfa is well-adapted to such conditions because its deep root system, allows it to use deeply stored water. In addition, it can withstand drought quite well (with very little growth), then grow again after rainfall (Downes 1970).

6. TYPES AND USES OF CROP PRODUCTION EQUIPMENT

Depending on the crop production system employed, one or more types of equipment will normally be required to prepare a satisfactory seedbed, plant seeds, control weeds and volunteer crop plants, apply fertilizers, and conserve soil and water resources. The equipment of a subsistence farmer may be as simple as a hoe for seedbed preparation, a pointed stick for planting, and a cutlass or machette for weed control. In contrast, the farmer employing a modern high-technology system usually has a wide array of equipment including one or more tractors, ploughs, harrows, land planes, sprayers, fertilizer applicators, planters, cultivators, and various other types of specialized equipment.

A vast array of equipment is available for all production systems. The type used in a particular system at a given location depends on such factors as availability of credit, equipment, spare parts, fuel, lubricants, trained operators, and repairmen; initial cost and expected returns; soil conditions; crops grown; and producer preferences. Some types of equipment have been mentioned in previous sections of this report. A detailed discussion of all available equipment is beyond its scope; therefore, the emphasis is on typical hand, animal-drawn and tractor powered equipment for use in clean and conservation tillage systems.

6.1 EQUIPMENT FOR CLEAN TILLAGE SYSTEMS

In a clean tillage system, objectives are to cover all plant residues and to prevent growth of all vegetation except that of the crop being produced. These objectives are equally applicable to hand, animal-drawn and tractor powered production systems. However, the method of attaining these goals varies for the different systems.

6.1.1 Hand Powered System

The basic hand implements for primary tillage are spades, forks and hoes (Figs. 2, 3). Because of the limited power available, soil loosening or turning is relatively shallow, but may be up to 25 to 35 cm in some cases (Hopfen and Biesalski 1953). With hand implements, crop residue incorporation is difficult; therefore, if large amounts are present, they are often burned or removed for other purposes before the soil is tilled, which is not conducive to soil and water conservation, as stressed in previous sections.

Hand implements for preparing the seedbed and for controlling weeds include hoes, cutlasses, machettes, rotary harrows, rotary weeders, ridgers and cultivators (Figs. 2, 3, 4, 111). Weeds may also be pulled by hand. Herbicides are rarely used. Mineral fertilizers are not commonly used, but when used they are mostly applied by hand or with simple equipment (Fig. 112). Manure is usually spread with forks (Hopfen and Biesalski 1953).

Crops are seeded by hand broadcasting; dropping seed into holes or shallow furrows opened with hoes, spades, sticks, etc.; or with hand-pulled or pushed seeders or drills (Figs. 112, 113). As a rule, broadcasting is less desirable than other methods because it wastes seed, makes cultivation and weed control more difficult, and limits the opportunity for inter-cropping and other intensive crop production techniques (Hopfen and Biesalski 1953).

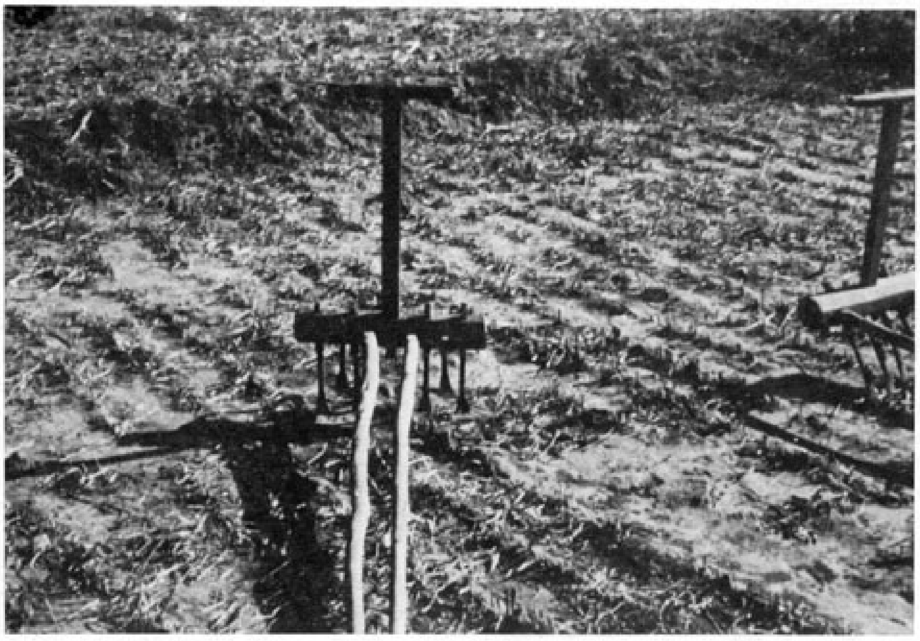

Fig. 111 Hand or animal-drawn cultivator in India (photo provided by B.A. Stewart, USDA-ARS)

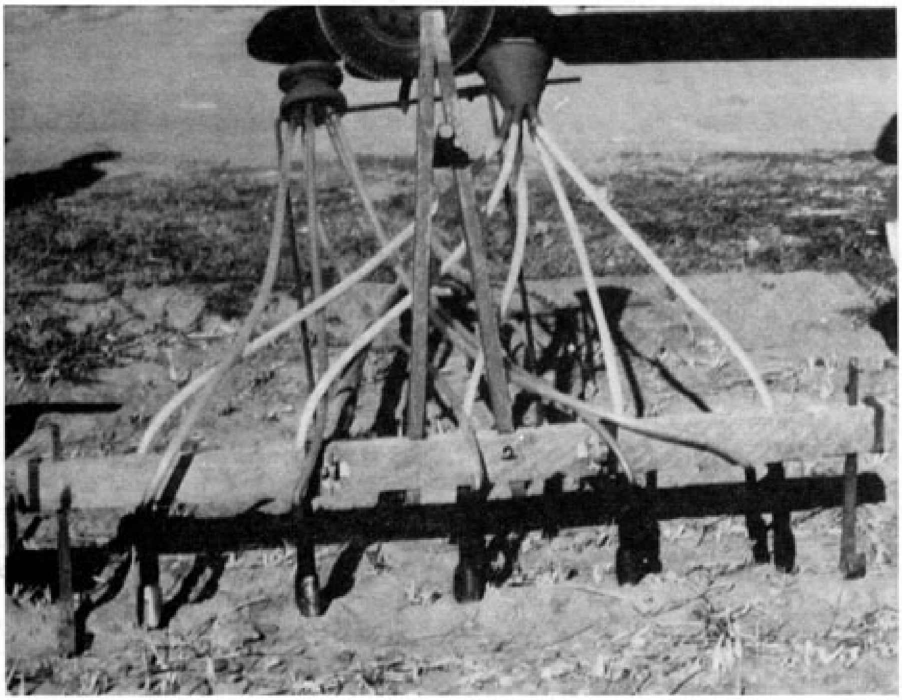

Fig. 112 Hand operated fertilizer applicator and seeder in India. The implement can also be adapted for use with animals (photo provided by B.A. Stewart, USDA-ARS)

Fig. 113 Using a hand seeder to seed grass to aid in erosion control in Tunisia (FAO photo)

6.1.2 Animal Powered System

Implements for primary tillage with animals (Figs. 5, 60, 114) have been classified as breaker, breaker-turning (or digger), and cutting-turning (Hopfen and Biesalski 1953). Breaker ploughs (Figs. 5, 114) are primarily for loosening soil, but are not effective for controlling weeds or covering vegetation and manure. Consequently, their use for clean tillage is limited to areas without crop residues (removed or burned) and where weeds are not a problem (grazed, burned, etc.).

Breaker-turning ploughs (Fig. 60) loosen soil and partially or completely invert the surface layer. Mouldboard and disk-type breaker-turning ploughs are available. Disk ploughs have the advantage of passing over rocks and roots in the soil without damage (Hopfen and Biesalski 1953). However, disks may leave the soil in a highly erodible condition due to limited surface roughness and may cause soil compaction if used when there is too much water in the profile. Neither of these ploughs, as well as the cutting-turning plough (next paragraph), should be used on dry sandy soils where the potential for wind erosion exists. Ploughing under such conditions seldom results in adequate soil roughness and aggreqate stability to provide protection against erosion. When operated in a moist sandy soil, sufficient cohesion may be achieved to provide protection against wind erosion. Further protection against wind erosion can be achieved by using a modified mouldboard plough which only partially inverts the surface layer and, thereby, retains some crop residues on the soil surface.

Cutting-turning ploughs have a share to cut the soil and a mould-board to invert the surface layer. Because they cut rather than break the

Fig. 114 Animal-drawn ploughing in front of the Colossi of Memnon near Luxor, Egypt (WFP photo, issued by FAO)

soil, these ploughs are more effective for weed control than the breaker-turning plough. A variation of the cutting-turning plough, which turns soil in one direction, is the lister (or ridger) plough, which forms alternate ridges and furrows by turning soil in two directions (Hopfen 1969). Ridges formed by lister ploughing provide protection against water erosion when ploughing is on the contour and against wind erosion when the ploughing direction is perpendicular to the prevailing wind direction.

Secondary tillage for seedbed preparation and weed control is performed with animal-drawn harrows and cultivators (Figs. 6,111). Fertilizers, when used, are usually applied by hand or simple equipment and manure is spread with a fork. Herbicides are rarely used. Seeding is by hand or with animal-drawn planters or drills (Figs. 63, 92, 112) which are often larger versions of the seeders available for hand use. Some seeders have interchangeable seed plates that permit planting of a wide variety of different crops (Hopfen 1969). Weeds are controlled after planting by animal-drawn cultivators, hand hoeing or hand pulling.

6.1.3 Tractor Powered System

The types of equipment used with small tractors are almost identical to those drawn by animals. However, the sizes and methods of attachment, depth control, etc. may be greatly different. In addition, tractors permit the use of machine-powered rotary tillers which was not possible without tractors. Such tillers are widely used with small, single-axle tractors (Fig. 62) and larger versions are available for larger tractors. Fertilizer, when used, may be applied with special equipment and manure may be spread by a tractor-drawn spreader. Weeds may be controller with herbicides in some cases, but are normally controlled by cultivation and hand hoeing.

The sizes or equipment increase as tractor sizes increase. In addition, a greater variety of equipment is normally available for use with medium to large tractors than with small tractors, and the larger tractors have enough power to combine two or more operations (Siemens and Burrows 1978).

Primary tillage is often performed with a mouldboard plough (Figs. 71, 115), which covers most residues, but results in a relatively rough surface if the soil is not too sandy and dry. Secondary tillage after mouldboard ploughing may be with tandem disks, sweep ploughs, harrows, sweep-rodweeders, or listers. Disk ploughs or harrows, listers, chisel ploughs, subsoilers, sweep ploughs and listers are also used for primary tillage in some cases (Siemens and Burrows 1978).

Fig. 115 Reversible mouldboard plough

Disk implements include disk ploughs, one-way disks, tandem disks and offset disks. Although they are highly effective for controlling weeds, they incorporate about 50 percent or more of surface residues at each operation and leave the surface relatively smooth (Fig. 16). If used three or four times, the surface is usually devoid of residues and the soil thus becomes susceptible to erosion (Fig. 116) unless the surface remains rough or can be roughened or ridged with a chisel, sweep plough or lister during a secondary tillage operation. A chisel is frequently used on disked land to loosen the soil more deeply than can be accomplished with a disk implement. For maximum soil loosening and duration of this loosening, chiselling should be done while the soil is relatively dry.

Fig. 116

Erosion by water on disk ploughed land (USDA-Soil Conservation Service photo)

Listers are used for primary tillage in some cases for row crops such as cotton, sorghum, maize, groundnuts, etc. Sometimes, the land is listed twice, with the second operation reversing the position of the furrows and ridges. Listing on the contour helps control water erosion, while listing perpendicular to the direction of prevailing wind aids control of wind erosion. Weeds on lister-ploughed land are controlled with sweep cultivators and sweep-rodweeders (Figs. 77, 81).

In situations where surface residues and weeds are limited or absent, a chisel can be used for primary tillage to loosen the soil. Chiselling requires less power than mouldboard ploughing and results in a rough cloddy surface that minimizes erosion, especially by wind (Fig. 34). Where chisels are used for primary tillage, secondary tillage is often with sweep ploughs or listers. Normally, disk implements should not be used because they greatly reduce surface roughness. However, a disking may be necessary to control a severe infestation of weeds, such as one that may develop after a prolonged rainy period.

A special problem on clean-tilled land is the disintegration and breakdown of soil aggregates and clods during rainstorms, especially on sandy soils, which results in a relatively smooth surface and can result in wind erosion within a few hours after the rainstorm. In such cases, some type of emergency tillage may be needed to control erosion and prevent sandblasting of crop seedlings by wind-driven sand.

The objective of emergency tillage is to roughen the surface so that wind speeds at the surface are reduced sufficiently to minimize erosion. Equipment suitable for emergency tillage includes chisels, rotary hoes and sandfighters (Fig. 117). Chisels are operated at shallow depths (5-10 cm) and are spaced 1-2 m apart. Thus, damage to crops, if present, is slight. Rotary hoes and sandfighters are implements that break the crust and leave clods on the surface. All such implements are usually wide and are operated at relatively high speeds and can thus cover the land rapidly when soil conditions become favourable after a rainstorm.

A range of equipment is available for applying manure, mineral fertilizers, herbicides, etc. in tractor powered systems. Manure may be applied with tractor-drawn manure wagons (Fig. 118) or with specially designed trucks, each with built-in spreaders. Various equipment is

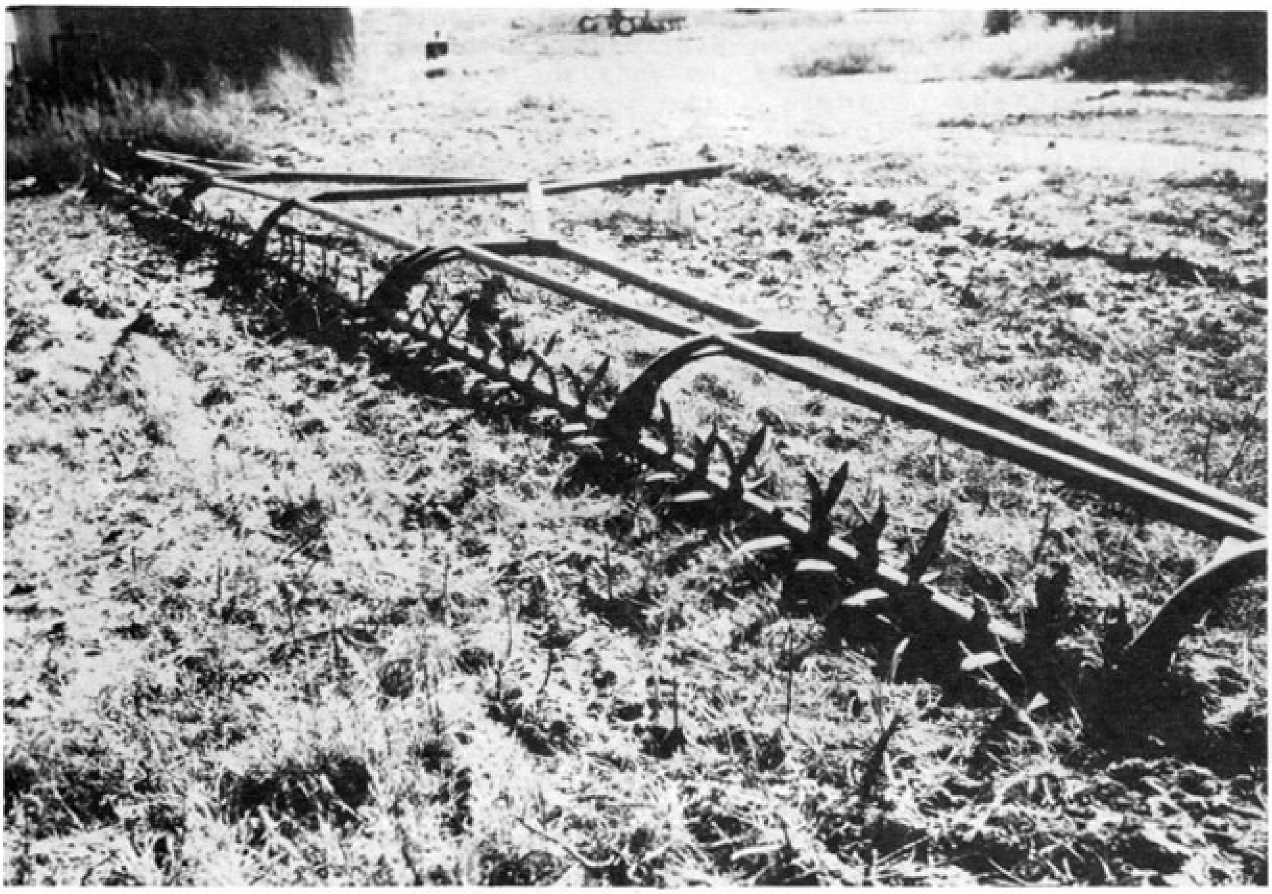

Fig. 117 Sandfighter

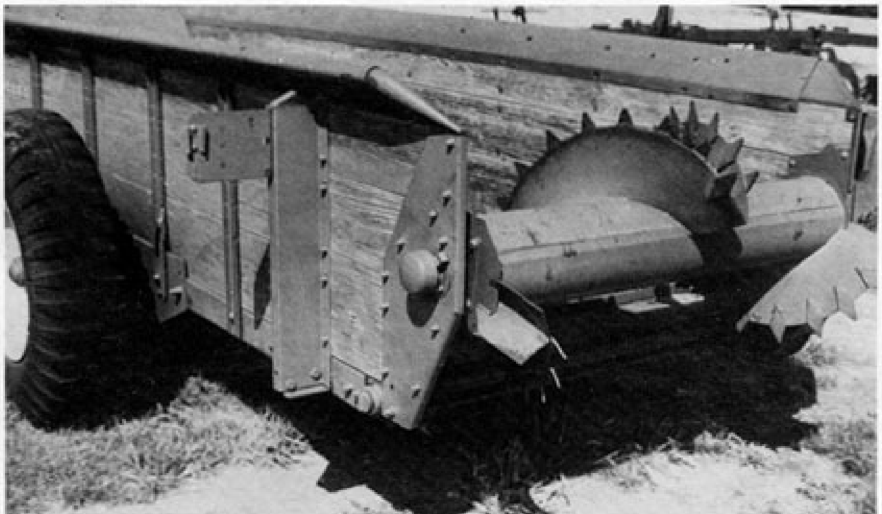

Fig. 118 Manure spreader

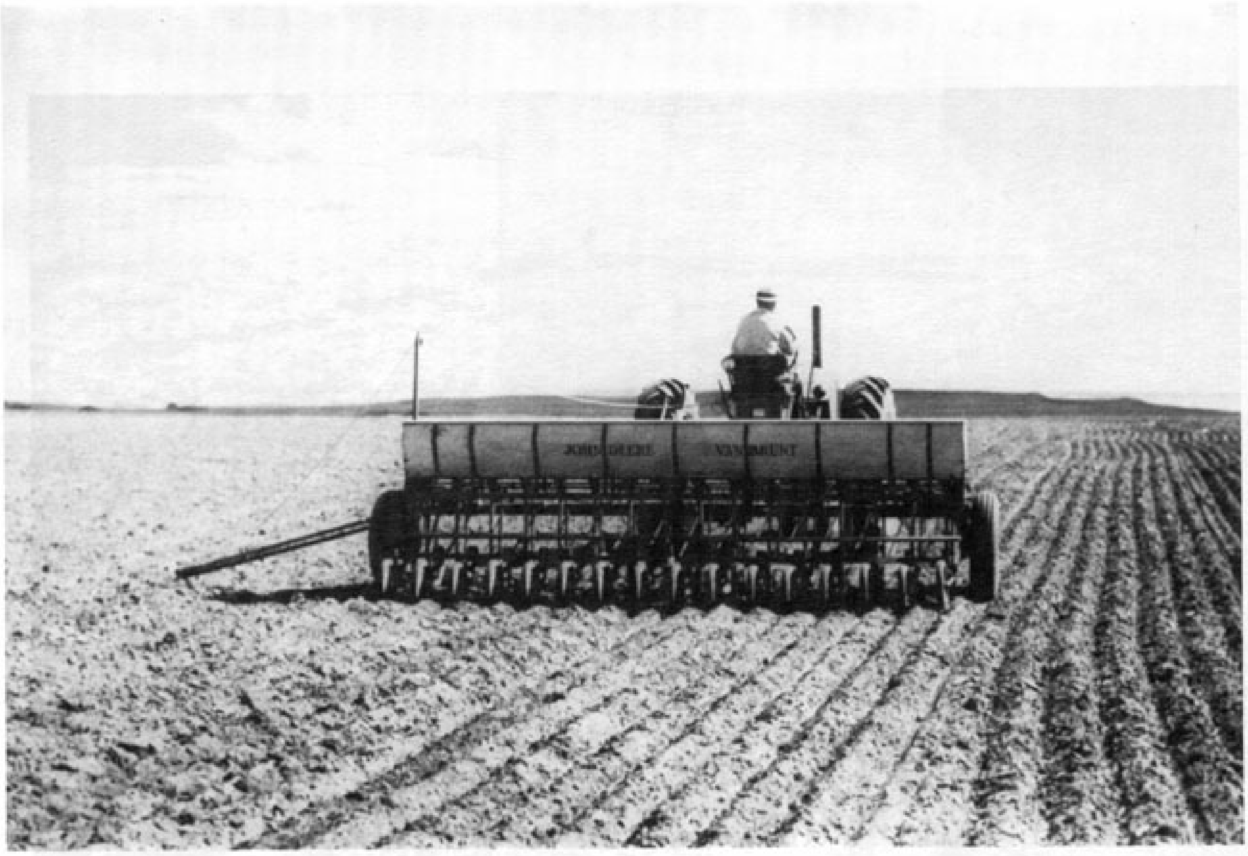

Fig. 119 Crop seeding with a semi-deep furrow drill. The ridges help control erosion (FAO photo)

Fig. 120 Seed drill with narrow row spacing. Heavy press wheels provide seed-soil contact for good germination (FAO photo)