Conservation tillage I

Management practices for animal drawn systems in Tanzania

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Preface

Conservation tillage I: Management practices for animal drawn systems in Tanzania brings out the critical issues, farming system perspectives, technological options and experiences on conservation tillage in eastern and southern Africa. The preparation of this book is the result of a conservation tillage training workshop held at the National Dryland Farming Research Centre, Katumani, in Machakos, which is one of Kenya Agriculture Research Institute’s (KARI) research centres in Kenya.

The workshop was arranged with the support of the Ministry of Agriculture (MoA) in Kenya, Regional Land Management Unit (RELMA), National Dryland Farming Research Centre, Katumani, and University of Nairobi. The workshop’s objective was to share experiences on conservation tillage practices and use of implements. The participants were drawn from stakeholder organizations in Ethiopia, Kenya, Tanzania, Zambia and Zimbabwe.

This book attempts not only to present conservation tillage country papers but also to raise critical issues and options on the transition to conservation tillage. It provides the basis for a conceptual framework on conservation tillage as a production system. It also represents the shift in thinking in conservation farming efforts within the region.

This book also provides the necessary information for the formulation of conservation tillage initiatives and networking within the region. It is expected that every country will establish a conservation tillage network and that these networks will have linkages with regional and international stakeholder organizations like RELMA, the International Soil Tillage Research Organization (ISTRO), the Food and Agriculture Organization of the United Nations (FAO) among others.

Special thanks go to all those resource persons that participated in the training sessions. Specific thanks go to George Okwach, National Dryland Farming Research Centre, Katumani, Mwamzali Shiribwa, MoA in Kenya, Johan Rockström, RELMA, and Elijah K. Biamah, Gabriel Mukolwe and Kipruto Cherogony, University of Nairobi for their individual contributions.

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1 Introduction

1.1 The starting point

Crop yields in sub-Saharan Africa of maize, sorghum and millet are approximately 4–5 bags/acre (about 1,000 kg/ha) in the smallholder rainfed farming sector. In many areas yields have dropped to 2–3 bags/acre due to land degradation and hydro-climatic hazards.

This is characteristic of vast semi-arid areas of Tanzania and eastern Africa in general. Crop yields in these areas are extremely low—well below their genetic potentials. In fact, on-farm yields could be 4 to 5 times higher than the current levels even in semi-arid areas. In sub-Saharan Africa, the current low yields have serious implications for the future. Present yields have to double if demands for food by the rapidly growing population are to be met (Rockström, 1999).

Unfortunately, the yield level trend shows no clear signs of improvements (rather the opposite in many regions). There is a widening gap between the potential and the actual production levels. What has gone wrong, and what can be done to turn this vicious yield spiral around?

There is much evidence to suggest that conventional tillage using the mouldboard and disc ploughs constitutes one important cause of soil degradation and subsequent yield decline. Conservation tillage offers a window of opportunity to convert degraded soils into productive soils, and thereby improves crop yields and reduces land degradation. The experience from conservation tillage in Africa, and other regions of the world, are encouraging to such an extent that a Presidential Task Force Meeting in September 1999, concluded that conservation tillage should be promoted nationwide as a priority activity in Tanzania. This report is a starting point to facilitate the accomplishment of this important and wise decision.

1.2 The challenge: Improving soil and water productivity

An important explanation to the vicious yield spiral in many farming systems in Tanzania specifically, and in sub-Saharan Africa in general, is a progressive and persistent decrease in soil fertility and available soil moisture for plants. This decrease is largely due to land management practices that are not adapted to the environment, and to the cropping patterns used by the farmers. The result is persistent low crop yields and excessive soil erosion caused by surface runoff.

A major cause of this land degradation is intensive soil preparation by hoe or plough, which together with the removal or burning of crop residues, leaves the soil exposed to climatic hazards such as rain, wind and sun (Benites et al., 1998).

Conventional tillage using ox- or tractor-drawn ploughs has over the years been perceived as the indicator of farm systems modernisation in developing countries. However, it is becoming more apparent that the ploughing techniques developed in temperate regions, which have gentle rains and low wind and water erosion, can have serious adverse effects on the long-term productivity of erosion-prone tropical soils. Some of the major long-term negative side-effects on soil productivity from conventional ploughing are:

- Compaction problems resulting in impermeable hardpans.
- Increased combustion of organic matter due to increased aeration (due to tillage), and periods during which the land is bare and the soil exposed to solar radiation.
- Increased water and wind erosion.
- Loss of soil water due to increase of evaporative surfaces and runoff.

Regarding soil fertility, insufficient soil nutrients often constitute the primary limiting factor to crop growth, in addition to water scarcity especially in the drylands. This is explained by the inherent low fertility of some of the major soils in the region, and the progressive mining of soil nutrients. It has been estimated that there
is a large net loss of soil nutrients each year in farming systems in several countries in eastern and Southern Africa. For example, in the Kenyan highlands, the average annual losses have been estimated to 70 kg/ha of nitrogen (N), 7 kg/ha of phosphorus and 50 kg/ha of potassium (Stoorvogel and Smaling, 1990). Fertiliser use in sub-Saharan African agriculture is the lowest in the world, with an average of 11 kg of fertiliser applied per harvested hectare.

This mining of the soil of its nutrients is a result of the abandonment of shifting cultivation practices with long fallow periods to restore soil fertility, in favour of a continuous plough-based cultivation.

In many semi-arid farming systems in Tanzania, and in other sub-Saharan African countries, a large proportion of the rainfall never becomes available to the cultivated crops. The reason is that, on average, about 15% to 25% of the rainfall never infiltrates into the soil, but is lost as surface runoff. This is a result of high intensity rainfall events on crusted soils, and due to compacted hardpans originating from decades of ploughing. Evaporation losses may also account for 50% of the rainfall, especially where mulching is not practised and canopy cover is low. Drainage problems are experienced even in the dry lands, due to the poor water uptake capacity of the crops.

In general up to 85–90% of the rainfall is not used for crop production in semi-arid farming systems in sub-Saharan Africa. This means that there is a large scope for improvement!

The foregoing pinpoints the necessity to address water constraints together with soil nutrient constraints. It also suggests that different water harvesting technologies, which lower the risk for crop failure, can function as an entry point for successful efforts towards increasing investments in soil nutrients.

Conservation tillage systems have the specific objective of solving these two problems, by (1) securing a maximum infiltration of rainfall where it falls, and (2) enabling efficient soil fertility management through spot application of soil nutrients.

1.3 Crop productivity trend in farming systems of the region

A typical example of the devastating effect of the ploughing-only culture in semi-arid areas is to be found in Ismani, in the Iringa region of Tanzania. In the 1960s Ismani was the grain basket of Tanzania. But it can hardly feed itself today. The main reason for this state of affairs is the exhausted and compacted soils, created by excessive ploughing and overgrazing through the years.

A recent United Nations Food and Agriculture Organization (FAO) sponsored study on mechanisation in Dodoma and Morogoro showed that these two regions had experienced similar land productivity decline as that of Ismani. A final workshop on the study results recommended a shift from the ploughing-only strategy to a dryland farming approach that is based on conservation tillage systems.

Unfortunately, the Ismani, Dodoma and Morogoro experiences are not unique. Land degradation resulting from the use of ploughing is common throughout Tanzania, Kenya, Zambia, Zimbabwe, Mozambique, Botswana, Uganda, South Africa etc. The Machakos area in Kenya is famous for its successful soil conservation programmes. However, the beneficial effects obtained early in the programme have greatly reduced, and farmers have been puzzled by the low crop yields during the last decade. During a recent (1998) regional conservation tillage workshop at the Kenya Agricultural Research Institute (KARI) National Dryland Farming Research Centre, Katumani, Machakos, it was shown that both the research station and the farmers were facing the same low-productivity problems. An exercise to examine the root cause of the change clearly demonstrated that the area was suffering from the negative effects of continuous ploughing (compacted soils, ploughpans and crop water stress). The only way to reinstate production to previously good and stable yield levels over time would be to change the tillage practice and open up the soils.
Ridge cultivation by hand dominates in Malawi. A recent study in Malawi (Douglas, 1999) shows that the cut and scrap action of a hand hoe creates a compacted layer under the ridges, which prevents the infiltration of rainwater and penetration of plant roots. Even if the ridges were constructed along the contour, there was serious erosion between the contour bunds. It was evident that breaking the pan was a precondition to restoring production to a sustainable and satisfactory level.

An example of the negative effect of ploughing is in Zimbabwe, where maize yields in the communal areas are as low today as they were at the beginning of the twentieth century. This brings into question what research and extension have achieved during the past 100 years. Similarly, in Botswana, conventional ploughing and high planting densities (roughly 80 x 30 cm), have resulted in low yields of maize, and high risk of complete crop failure during years with severe dry spells. However, conservation tillage, using permanent, deep tilled, planting strips with reduced planting density, has given higher average yields, and much lower risks of losing the crop during dry spells (G. Shone, RELMA, Nairobi, pers. comm., and G. Nilsson, private farmer, pers. comm.).

1.4 The intention of the report

As will be shown in this report, there are many documented examples of successful conservation tillage practices in eastern and Southern Africa. Under such tillage systems, crop yields have increased through the conservation of soil, water and nutrients, and draught power needs have been reduced (Elwell, 1993; Oldreive, 1993; Vogel et al., 1994).

Despite these successes, and the increased adoption of conservation tillage in other parts of the world, such as North and South America, the adoption among smallscale farmers in eastern and Southern Africa has been very low. On the other hand, commercial farmers in Zambia, Zimbabwe and Tanzania have seen the potential of conservation tillage as a way of building up land productivity, and reducing labour needs and production costs, especially in those semi-arid areas sensitive to land degradation (Oldreive, 1993).

The objective of this report is to assist in building capacity among extension officers, farmers and other professionals to promote animal drawn conservation tillage among smallholder farmers. It provides a practical guide on how to introduce an appropriate animal draught power technique for conservation tillage in semi-arid areas. Conservation tillage is a new subject to most agricultural staff and farmers in Tanzania. This report, therefore, opens with an extensive introduction to the topic, with a view to explaining the urgency of embarking on a radical change in the ADP promotion methodology.

The recommendations in this report are based on field experiences with farmers, extension staff and researchers on testing and developing conservation tillage systems in semi-arid districts of north-western Tanzania. More specifically, it builds on work conducted by the Sida-supported Land Management Programme (LAMP), together with the Soil Conservation and Agroforestry Pilot project in Arusha (SCAPA) on dryland farming in six semi-arid Districts (Babati, Kiteto, Simanjiro, Singida Rural, Arumeru and Arusha Urban) during the period between 1995 and 1999. These are districts where the philosophy of farming is centred on a common minimum risk strategy of avoiding crop and livestock failures.

The second experience is from the on-going development of conservation tillage systems together with farmers in Arusha and Arumeru Districts. This work is based on a partnership between farmers, SCAPA, LAMP and the Regional Land Management Unit (RELMA). In these on-farm trials, conservation tillage systems are tested under different agro-ecological zones, ranging from semi-arid conditions on flat semi-pastoral land, to sub-humid conditions on steep, well-conserved crop fields on the slopes of Mount Meru.

In summary, the conservation tillage work by LAMP, SCAPA and RELMA together with farmers in north-western Tanzania, has generated much knowledge, and has raised the awareness of the need for sustainable

1 In the USA an estimated 40% of the farmland is under some form of conservation tillage system.
and productive animal mechanised farming systems in the semi-arid areas in the region. In addition, there is knowledge on the importance of cover crops in conservation tillage, based on joint work with the GTZ-supported Agricultural Mechanisation Management Project of the Tanganyika Farmers’ Association (AMM/TFA).

It is important to note at the outset of this report, that there is still much work required before comprehensive guidelines can be given to the smallscale farmers of different agro-ecological zones. However, the knowledge generated so far, with farmers, extension and research is enough to confidently give appropriate recommendations that could result in radical improvements in crop production as they are based on sound basic farming principles. These recommendations need to be adapted to fit the local conditions. This report should, therefore, not be seen as a blueprint for conservation tillage in all of Tanzania. It is a technical handbook that gives the principle steps that can be taken to adopt conservation tillage, and should be read as a book that raises the awareness of all stakeholders on the role conservation tillage can play in the efforts of improving the agricultural sector in Tanzania.

The report should enable the direct implementation of conservation tillage on farmers' fields. However, it is important to note that adaptive experimentation with the farmers will be required for each different site, to mould the new tillage practices into the specific farm context.

Furthermore, this report concentrates more on the animal drawn tillage technique, and should be linked with the RSCU Technical Handbook No. 7: Soil Conservation in Arusha Region, Tanzania for wider coverage. Moreover, the recommendations of the LAMP/SCAPA gender guidelines of 1999 should permeate the training and development activities of conservation tillage. The report is designed for the needs of the extension staff. It is both a handbook and a source book. It is also an essential document for agricultural learning institutions, research staff, land management programmes and decision-makers in agricultural development. It is possible that the recommendation in this report will be found valid for many semi-arid locations in Tanzania, as well as in other parts of eastern and Southern Africa.

1.5 Linking conservation tillage to soil and water conservation

The control of soil erosion was, for decades, the major challenge in most extension efforts dealing with land management. SCAPA was established in 1989 with the primary objective of reducing land degradation by means of soil conservation and tree planting. This approach has been very successful, not only in Tanzania, but also in Kenya (as in Machakos District), Uganda (Mbarara) and Ethiopia. Conservation efforts have had the important benefit of slowing down, and in some cases even altering, the yield decline among farmers. However, these improvements are not enough where yield levels rarely exceed 1 t ha⁻¹. There is an urgent need to address land productivity. One way of doing this is through integrated land management, where soil conservation forms only one component on a larger whole.

As will be shown in Chapter 9, farmers expressed the view that soil conservation combined with the use of organic manures, resulted in yield increases from 1–3 bags/acre (90 kg bags) to 5–6 bags/acre. The trials using conservation tillage on conserved land, yielded 20–25 bags/acre. This indicates the potential of increasing yields by combining conservation with tillage and the use of fertiliser.

In the context of Tanzania, conservation tillage is addressing what management system to adopt between the faanya chini terraces to improve soil productivity and increase crop yields.

With a proper but simple conservation tillage technique, it is possible to control runoff and erosion successfully in fields with slopes up to 12–15%. This type of land characterises the vast majority of the cropped land in Tanzania. High potential flood plains and mountainous areas account for approximately 10% of the land area of Tanzania.

It must be acknowledged that ploughing, as a tillage technique, can result in poor infiltration and soil compaction, thus making even almost flat land become highly susceptible to runoff, serious soil erosion, and
large water and soil fertility losses. Extensive conservation measures are, therefore, required to overcome the problem caused by ploughing. This is a particularly crucial issue, as 90% of the cultivated land is ploughed 1–3 times per season in most cropland in north-western Tanzania. The commonly observed trend is that the rate of soil destruction exceeds conservation efforts. There is a feeling that one is fighting a losing battle to a large extent in the desire to promote the development of sustainable and highly productive farming systems.

An animal-drawn tillage practice like ridging (with a ripper/ridger) along the contours is a good entry point for an appropriate land husbandry programme. The slope does not affect runoff if the ridges are well laid out and properly constructed. Secondly, the application of an efficient cropping system follows in the ranking of importance for farming systems improvements. Thereafter, the soil conservation measures can be applied (if required), to safeguard maximum productivity and sustainability. Practically, it is hard to separate tillage and soil conservation into two separate activities, since they are closely integrated into the conservation tillage concept.

Conservation tillage implies that mechanisation/tillage and soil conservation staff work together as one team in promoting the technique. The current separation of these disciplines, often induced by donor influence, has hampered both development and implementation of sustainable and productive farming systems for the semi-arid tropics.

1.6 The rationale for conservation tillage among smallholder farmers

1.6.1 Availability of arable land

Approximately two-thirds of the rural population in Tanzania live in the high potential areas that cover about 10% of the total land surface. Most of this land is already occupied and the cost of land is high. Half the total population of 33 million people is below 15 years of age. This means that there is a large number of potential farmers looking for new and cheap land. The less potential semi-arid areas are the only alternatives for the majority of new land farm households.

Where land is available, the main dilemma is whether the commonly used farming techniques and land tenure systems can support the increased population in a sustainable way. It is evident that this is not so with the present cultivation practice that is based on ploughing. Ploughing is highly inappropriate for tropical semi-arid areas. This problem is more intricate where the pastoralist/agropastoralist modes of dryland farming appear to be the only alternative of meeting the future demands of feeding the nation.

1.6.2 Land allocation

Most farmers have a small homestead garden of 0.5 acre (about 0.2 ha; shamba la nyumbani) and farmland (shamba la mbali) on a 2–4 acre (0.8–1.6 ha) plot. The latter is situated at some distance (0.5 to several kilometres) from the village. There are large variations in number and sizes of fields per household. The management level is usually high at the homestead. However, the intensity of care on the farmland decreases with the distance from the village.

This spread of farmers’ fields complicates the use of good land husbandry practices. For example, conservation measures are applied almost exclusively to the homestead lands. It is difficult to protect soil conservation structures on the distant farmlands, especially after harvest.

Another complicating issue is the allocation of land in strips along the slope (catena) to ensure fair distribution of fertile soil. This has resulted to a habit of ploughing up and down the slope, as it is difficult and time-consuming to work across the slope. A precondition for sound land management is to till along the contour, which requires that farmers work together to realign the cultivation pattern.

Conservation tillage provides opportunities for improved land husbandry practices on all types of land, and this should minimise soil degradation and maintain fertility and productivity on large tracts of land.
1.6.3 Dealing with farmers’ risk management strategy

Farm specialisation is rare in many of the farming systems located in areas that are highly susceptible to drought. People have learnt, over long periods of time, that there are great risks involved in concentrating on few production activities. The security increases if one has a larger amount of activities and alternative modes of production. Specialisation gives a better yield during good years but could fail completely during adverse conditions. For example, the combination of crops and livestock is typical in semi-arid areas as it increases food security. Also, inter-cropping and planting of different crops at different time, reduces the risks of a complete crop failure.

It is evident that the minimum risk strategies become deeply rooted in the minds of farmers and livestock keepers, and any change in cropping/livestock practices must add to reduced risks and increased food security if they are to be acceptable. The risk of drought and dry spells guide farmers’ decisions in many semi-arid areas. It is therefore essential to remember, when discussing improved techniques with the farmers, that any new intervention must reduce the risks for crop water shortage. Conservation tillage is a very efficient way of minimising risks of crop water stress by assuring maximum infiltration, low evaporation losses and progressively increased water holding capacities of the soil.

1.6.4 Responding to farmers problems

Surveys carried out among farmers in north-western Tanzania clearly indicate the need and urgency to revise the current practices of soil management. High runoff, hardpan formation, and soil nutrient mining (all resulting in poor crop and biomass growth), are key constraints of concern for smallholder farmers in both crop and livestock production. A key issue, thoroughly discussed with farmers and extension staff in need of a quick and long lasting remedy, is how to allow rainwater to infiltrate into the soil. Humanity has caused these degradation problems. It is also essential for humanity to rectify them and restore soil productivity on large parts of affected agricultural land.
2 The principles of conservation tillage

2.1 Defining conservation tillage

Conservation tillage is generally defined as any tillage system with the objective of minimising the loss of soil and water, and having an operational threshold whereby more than 30% mulch or crop residue cover is left on the surface. In regions of sub-Saharan Africa, conservation tillage refers to any tillage system that reduces the draught power requirements for crop production, while at the same time conserving water, soil and nutrients. It should be clearly noted, however, that many professionals state (on good grounds) that mulching is a precondition for successful conservation tillage (in order to suppress weeds, reduce evaporation losses, and build up top-soil structure). This means that finding ways of assuring at least a minimum of mulch cover constitutes one of the major challenges for conservation tillage development in semi-arid areas of Tanzania.

Conservation tillage covers a broad range of tillage systems. Often, conservation tillage is associated with zero tillage or minimum tillage, among many other strategies. Zero tillage is the ultimate goal of any conservation tillage strategy. Successful zero tillage implies that the soil structure has returned so closely to the virgin soil state, that soil crusting, structural compaction and weed infestation pose very few problems. This is not often the case. Indeed, it is never the case when introducing conservation tillage on cropland that has suffered from decades of soil structural collapse due to conventional ploughing. Therefore, between the two extremes of conventional ploughing and zero tillage, there is a broad range of conservation tillage systems, which permit the farmers to use improved tillage on problem soils. The goal is to progressively restore virgin soil qualities.

For the purpose of this report, it is useful to see conservation tillage in simple terms as the abandoning of soil inversion (using the conventional mouldboard plough) in favour of alternative tillage systems that improve infiltration and soil productivity.

This means, for example, that conservation tillage may include intensive sub-soiling, followed by ripping, mechanised weeding, and then sowing into permanent planting lines. The end result may involve using animal traction more often than previously done under the conventional system. In such cases, the conservation tillage system is not defined as minimum, reduced, or zero tillage, but rather as an alternative tillage system with no soil inversion.

### Box 1.1: Defining conservation tillage within a Tanzanian context

Conservation tillage includes any tillage sequence that reduces soil and water losses relative to conventional tillage. It is often in the form of non-inversion tillage that retains a protective amount of crop residue on the surface. For the farmer, conservation tillage means abandoning the plough (generally, the mouldboard or disc ploughs) in favour of tillage practices that improves the availability of water and nutrients for the crops on the long term. The objective of conservation tillage is to increase water/moisture retention in the soil, increase organic matter into the soil and prevent soil erosion.

In general terms, the benefits of conservation tillage include:
- Better utilisation of rain water
- Moisture conservation due to crop residue coverage
- Reduction of soil erosion losses
- Increase of organic matter content of the soil
- Ease of root growth in the soil, which ensures maximum water nutrient uptake into the plant.
From a rural development perspective, this means that conservation tillage is not a new production system for the smallscale farmers in sub-Saharan Africa, but rather a development of the original farming practices based on shifting cultivation and long fallows. The basic rationale of shifting cultivation was to permit the perennial fallow vegetation to lift up soil nutrients from deeper soil layers, improve soil structure, and return organic matter in order to develop the chemical and structural properties of the upper A-horizon. Except for the burning practices, generally linked to this slash-and-burn system, the same objectives apply to conservation tillage. Indigenous developments from long-fallow based farming systems can be found today, like zero-till systems with planting pits (such as zai pits in Burkina Faso and matengo pits in Tanzania).

2.2 Conservation tillage: A return to virgin quality of soils

Farmers know well that virgin land has the best soil, and that the fertility level drops when such land is put under cultivation. The rate of soil fertility decrease depends on many factors, but it can be a rapid process in semi-arid tropical areas with a thin top soil and poor management. The good qualities of a virgin soil decline rapidly to its minimum yield potential within a few years of cropping in most parts of Tanzania and elsewhere in Africa. In fact, most agricultural land is reduced to its minimum agricultural potential through degradation of the soil structure at an alarming rate. However, it is possible to control and maintain soil fertility on cultivated land at a high level with appropriate cultivation practices. Conservation tillage could be an important component of this process.

The basic aim of conservation tillage is to apply tillage practices, which ensure maintenance of the virgin soil quality. In brief, it involves minimum destructive tillage, which leaves the crop residue on the surface, thus enhancing good rainwater infiltration and crop root development, and manages the organic matter content, fertility and soil structure well. Improved crop husbandry practices, like crop rotation, inter-cropping and cover crops are also essential components in this respect.

Another important aspect of conservation tillage is that of bringing an exhausted, compacted, and drought-sensitive soil back to a potentially and much higher production capability. It is predicted that the restoration process is the most important aspect due the vast areas of degraded soils. This applies to most of the cultivated land in Tanzania, and Africa in general.

The photograph in Figure 2.1 illustrates one example, of the potential of conservation tillage under practical farming conditions to restore poorly managed soils quickly to almost virgin quality in Babati District. The field in the front shows a maize field ploughed in the traditional way. The rear field is exposed to conservation tillage (sub-soiling) and application of farmyard manure during the first season. It is important to realise that these two farmers’ fields had been cultivated in the same way for many years. The tillage operation in the rear field has opened the heavily compacted soil enabling rainwater to infiltrate and crop roots to go deep into the soil. Both fields were planted with Kilima maize variety on the same day.

The ploughed field yielded 4 bags/acre (900 kg/ha), which was normal for this location for the 1995/96 season, while the sub-soiled field produced 22 bags/acre (5,500 kg/ha). The following season, the farmer who cultivated the field in front sub-soiled his field and the difference in yield was almost zero.

Trials at the Waang’waray Demonstration Farm showed another good example of the potential of restoring production capacity of damaged soils through conservation tillage. This farm was established on previously deserted land with heavily degraded and eroded soils. Table 2.1 presents a summary of the dryland farming demonstrations from the four seasons of 1995/96 to 1998/99. The starting point was an equally degraded soil in 1995/96 with inherited low production capacity common in the area. All fields, including the controls (18 plots of average 229 m² each), were protected by stabilised fanya juu soil conservation bunds. The soil was a sandy clay loam with a pH of 5.4 and an organic matter content of 2.67% at the top 15 cm. The crop yield recorded was based on the total plot yield.
Table 2.1 Dryland farming demonstrations of maize at Waang’waray, Babati

<table>
<thead>
<tr>
<th>Treatment</th>
<th>FYM (t/ha)*</th>
<th>95/96</th>
<th>96/97</th>
<th>97/98</th>
<th>98/99</th>
<th>1995/96-1998/99 Average</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall (mm)</td>
<td>610</td>
<td>460**</td>
<td>2,498</td>
<td>400</td>
<td></td>
<td>2,498</td>
<td>323</td>
</tr>
<tr>
<td>1. Conservation tillage;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-soiling***</td>
<td>10</td>
<td>4,804</td>
<td>1,034</td>
<td>3,022</td>
<td>2,131</td>
<td>2,748</td>
<td>323</td>
</tr>
<tr>
<td>2. Conservation tillage;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-soiling***</td>
<td>-</td>
<td>4,074</td>
<td>827</td>
<td>1,282</td>
<td>725</td>
<td>1,727</td>
<td>203</td>
</tr>
<tr>
<td>3. Ploughing***</td>
<td>10</td>
<td>1,739</td>
<td>831</td>
<td>1,329</td>
<td>1,044</td>
<td>1,236</td>
<td>145</td>
</tr>
<tr>
<td>4. Control; Ploughing***</td>
<td>--</td>
<td>1,290</td>
<td>606</td>
<td>1,243</td>
<td>267</td>
<td>851</td>
<td>100</td>
</tr>
</tbody>
</table>

* Farmyard manure applied.
** 290 mm fell after planting.
*** Hand planting and hand weeding.

The grain yield was multiplied by 2, to obtain the approximate stover yield. It was further estimated that the root mass was equivalent to the grain yield, hence the total amount of biomass produced approximated the index.

It was concluded, from the Waang’waray study that a combination of opening up of the soil through deep tillage such as sub-soiling and farmyard manure was the most beneficial in transforming the poor soil into fertile land. The traditional system of ploughing-only performed badly even with soil conservation measures. The situation was improved with addition of farmyard manure. An interesting finding was that sub-soiling did very well only initially, when there was a bulk of accumulated nutrients in the soil that were quickly absorbed by the enlarged and more vigorous crop root systems. However, when these were depleted, the yield level dropped, indicating that improved tillage and soil fertility maintenance must go hand in hand.
2.3 Systems approach to conservation tillage

In the long term, the transition from conventional to conservation tillage involves a complete change in production systems. A sustainable conservation tillage system thus involves much more than just a change of implements. It also normally involves changes in cropping systems, timing of farm operations, and management of weeds, crop residues, and soil fertility.

It is true that drastic effects on timeliness of operations, rainwater harvesting, and land husbandry practices, can be achieved just by changing from the conventional plough to conservation tillage implements. Early planting, achieved using a ripper-planter attachment, has been shown to have a very significant impact on water use efficiency in farming systems in Zambia. Planting in parallel rows using a ripper enables mechanised weeding, which is difficult in plough-planting systems. Sub-soiling breaks ploughpans, giving immediate dramatic effects on infiltration of rainfall into the soil, and increased crop yields. Ripping along contours reduces soil erosion to the extent that on gentle slopes soil conservation structures become less important.

These examples motivate a change from the conventional plough to conservation tillage. This is an important extension message in semi-arid areas with limited crop residues. In the long term though, a systems approach is needed in order to achieve a persistent and sustainable build-up of soil productivity.

It is advantageous to view the change from conventional ploughing to conservation tillage as a transition from one land management system to a completely new technique. Table 2.2 gives some of the decisions that have to be made by a farmer who wishes to abandon the plough in favour of conservation tillage.

A systems approach means that as soon as the plough is changed to an alternative tillage implement (be it rippers, sub-soilers, hand-hoeing or zero tillage), most other farm operations have to be modified into a new production system. In semi-arid areas of Tanzania, where livestock play an important role in the farming system, mulching and livestock management are especially important, and must integrate with tillage changes. For example, in the areas in north-western Tanzania where the experiences described in this report took place, farmers manage land in areas characterised by acute degradation problems. The villages are dominated by an agropastoral farming system, where livestock play a key role in the farm economy. As noted earlier, the total removal of crop residues, either by grazing animals or cut-and-carry systems, is one of the causes of soil compaction, land degradation and poor crop yields. Introduction of conservation tillage, requiring return of crop residues, needs a parallel development of livestock feeding strategies. How to balance livestock requirements of post-harvest grazing with the necessity of leaving some mulch in the field for successful conservation tillage, needs to be addressed.

As will be discussed later in the report, conservation tillage systems based on animal draught power involve a more intensive management of the draught animals. This includes draught power and the ability of the animal to walk in straight lines while establishing permanent planting lines. In many areas of Tanzania, donkeys are used for ploughing, and may be used to pull conservation tillage implements. Training and feeding of draught animals constitute integral parts of a conservation tillage system.
**Table 2.2** Example of a guide with options for the farm operations involved in shaping a conservation tillage production system for small-holder farmers in Eastern Africa

<table>
<thead>
<tr>
<th>Operation</th>
<th>Implements</th>
<th>Traction</th>
<th>Methods</th>
<th>Timing</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-soiling (25-40 cm depth)</td>
<td>Chisel plough</td>
<td>Tractor</td>
<td>Sub-soiler/ripper</td>
<td>Animal</td>
<td>Rows - ú 0.8 m apart deepening furrow by more passes in the same row</td>
</tr>
<tr>
<td></td>
<td>Sub-soiler/ripper</td>
<td>Animal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weed control (dry season)</td>
<td>Sweep Ripper/ripper/ripper</td>
<td>Animal, tractor</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tillage and planting</td>
<td>Chisel plough</td>
<td>Tractor</td>
<td>Ripper/ridger/ripper</td>
<td>Animal</td>
<td>Ripping at row-to-row distance (15-20 cm depth). Planting by seed drill/planter or by hand</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ripper/planter</td>
<td>Animal</td>
<td></td>
</tr>
<tr>
<td>Fertilisation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basal dressing</td>
<td></td>
<td>Manual</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topdressing</td>
<td></td>
<td>Manual</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planting cover crop</td>
<td></td>
<td>As planting of main crop</td>
<td>Manual</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water management</td>
<td>Ridger</td>
<td>Animal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tie maker</td>
<td>Animal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weed control in standing crop</td>
<td>Cultivator/Ripper/ridger</td>
<td>Animal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hand hoe</td>
<td>Manual</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-harvest treatment</td>
<td></td>
<td>Manual</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Operations:**
- **Sub-soiling**
- **Weed control**
- **Tillage and planting**
- **Fertilisation**
- **Water management**
- **Weed control in standing crop**
- **Post-harvest treatment**

** Implements:**
- Chisel plough
- Sub-soiler/ripper
- Sweep Ripper/ripper/ripper
- Chisel plough
- Sweep Ripper/planter
- Animal
- Tractor
- Manual

**Methods:**
- Sub-soiling
- Rows - ú 0.8 m apart deepening furrow by more passes in the same row
- Ripping at row-to-row distance (15-20 cm depth)
- Tillage of entire surface (20 cm depth)
- Seeding by seed drill/planter or by hand
- Planting by seed drill/planter or by hand
- Ripper can be fitted with wings for ridging.
- Ripper can be fitted with wings for ridging. Single and double yoke
- As planting of main crop
- Animal
- Animal
- Animal
- Animal
- Animal
- Animal

**Timing:**
- Dry season. Once every 2-3 years
- Dry season. Once every 2 years
- Any time after harvest
- One month to a couple of weeks before the onset of the rains.
- One month to a couple of weeks before the onset of the rains.
- As soon as crop is established
- As soon as crop is established
- This operation is possible with animal traction thanks to the row planting

**Comment:**
- Possibility of hiring tractor among several farmers
- Can be done at any row spacing. If ripper-planting is done, it is advisable to sub-soil at 90 degree angle from planting rows (except when slope is |
- Dry planting can be considered
- Dry planting can be considered
- Choose rapidly covering crop.
- Return of realistic amounts of mulch
- Crucial to add a late weeding operation to reduce weed infestation
3 Crop residue mulch and conservation tillage

3.1 Organic matter dynamics

Mulch is dead plant material (such as dry grass, straw, maize stalks, dry leaves, banana leaves, sugar-cane trash and other crop residues) that can be spread on a soil surface or placed around plant stems. Stubble mulching refers to a tillage practice where mulch remains partly covered on the surface. Dead roots, which remain in the field, are also an important part of the biomass of crop residue. The interaction between crop residue above surface and below surface is an important factor in the efficiency of crop residue mulch.

A fertility aspect linked to crop residue is the microbial biomass, which feeds on the organic substances. Generally, microbial biomass decreases through cultivation, resulting in less efficient nutrient cycling capability. Large microbial biomass (and organic matter content) is associated with large pools of available plant nutrients.

Grain yield is linked to transpiration and growth rate of a plant. This means that a high yielding crop usually has a larger biomass production than a low yielding crop of the same kind. For example, the maize stover yield is 2–3 times that of grain yield, and the root mass is about the same as the grain production. Thus, a maize grain yield of 1,000 kg/ha is equivalent to a biomass production of approximately 3–4 tonnes (t)/ha. If the crop yield is doubled to 2,000 kg/ha, the biomass production is in the range of 8–9 t/ha.

A unanimous cadre of soil experts emphasise the importance of covering the soil surface with crop residue mulch and cover crops to protect the soil and to maintain virgin soil quality in semi-arid tropical areas.

The importance of mulching is reflected in the formal definition of conservation tillage as a tillage system where at least 30% of the crop residue is left on the surface as mulch (SSSA, 1987). The aim is minimal disturbance of the soil through destructive tillage. An extreme is zero-tillage. A layer of mulch:

- Reduces the impact of rain drops, catches runoff water and improves rain water infiltration
- Reduces soil temperature and evaporation losses
- Suppresses weeds
- Provides organic matter and soil and crop nutrients
- Creates a living and fertile soil environment for sustainable and productive farming.

Most crop roots stop taking up water when the soil temperature exceeds 33°C. It is common to find a soil surface temperature of above 50°C in a bare soil at the time of planting. It is evident that a bare soil is hardly provides optimum conditions for establishing a new crop.

A precondition for a production level above the minimum production potential is that there is a balance between what is taken away from a field and what is added. Lack of fertilisation and removal of crop residue quickly reduces virgin soil in semi-arid areas to its lowest level of fertility. In addition to replacing nutrient losses, there is a need to maintain the soil structure and organic matter content. When land is put under cultivation, the organic matter content drops, but finds a balance that corresponds to the level of destructiveness of the farming system. Factors affecting the level of organic matter level are:

- Temperature
- Moisture
- Soil texture, soil structure and drainage class
- Crop residue, biological mass, manure
- Rotational practice
- Tillage.
The amount of organic matter in soils is a result of the balance between the gains and losses of organic materials. The changes can be presented as follows:

\[
\text{organic matter change} = \text{gains} - \text{losses}
\]

Gains are what are added in form of organic matter to the soil, while losses are due to mineralisation (breakdown), leaching, burning, and erosion.

The mineralisation rate of organic matter in a savannah soil is about 5% per year (Godwin, 1990). Table 3.1 gives an estimation of the relationship between residue addition (mineralisation rate of 5%) and resulting steady state organic matter content in the soil.

**Table 3.1** Steady state of organic matter content at a mineralisation rate of 5B

<table>
<thead>
<tr>
<th>Dry crop residue addition (kg/acre)</th>
<th>Organic matter steady state (%)</th>
<th>Mineralised N/ year (kg/acre)</th>
<th>Mineralised N/ year (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>225</td>
<td>0.5</td>
<td>9</td>
<td>23</td>
</tr>
<tr>
<td>450</td>
<td>1.0</td>
<td>20</td>
<td>50</td>
</tr>
<tr>
<td>675</td>
<td>1.5</td>
<td>32</td>
<td>80</td>
</tr>
<tr>
<td>900</td>
<td>2.0</td>
<td>41</td>
<td>103</td>
</tr>
</tbody>
</table>

k = nitrogen.


Comments on Table 3.1
The crop residue content of k is approximately 5B. If 560 kg of crop residue is applied per hectare annually, and nothing else is added, the soil ends up with a soil organic matter content of 0.5B. Annually, 23 kg k will be available for crop growth. A 2B organic matter level can be maintained in the soil if 2,240 kg residue/ha per year is added. The amount of k available to crops annually could then be 103 kg. Runoff and erosion reduce the steady state of organic matter content further, but the soil is protected well with the increased rate of crop residue. Burning results in low organic matter content. The rate of release of k in crop residue depends on factors such as climate, the freshness of the residue, and its C:k (carbon:nitrogen) ratio. Farmyard manure, compost and cover crops are important complements in maintaining and/or upgrading organic matter content and crop nutrient supplies. However, large quantities of farmyard manure and composts need to be applied to have any real effect on the soil organic matter content. Crop residues are best in maintaining and building up organic matter and biological activities in a soil. Farmyard manure improves crop yield and subsequently the amount of available crop residue, which can then be recycled into the soil.

It appears that leaving 30% crop residue coverage on the soil meets the requirement for a tillage method to be classified as conservation tillage, and assures a minimum acceptable level of organic matter from a maize production of 2,000 kg/ha in semi-arid Tanzania. However, the steady state organic matter content in the soil is only 1% with a maize production of 1,000 kg/ha (still keeping 30% mulch cover).

Mulch stubble left on the soil surface decomposes at a slower rate than a crop residue that is incorporated into the soil. Despite this, surface mulch enables the crop roots to absorb most of the released nutrients provided there is no runoff. The advantage with surface mulch is that it extends the time the soil is covered/protected. Worms, termites and other insects and organisms gradually move the organic matter down into the soil. This process strengthens aggregate and macro-pore formation and improves biological activity and weakening of any surface crust or ploughpan.

Organic matter increases availability of essential crop nutrients and soil minerals that can be taken up by the crop roots. Many deficiencies can be corrected by adding some organic materials to a soil. In this way a large source of insoluble nutrients in the soil can be accessible through simple organic matter management.
Mulch is an important source of crop nutrients, though if not carefully managed can seriously retard crop yield. When crop residue of poor quality decomposes, the microbes involved require nitrogen, which they take from the soil. The effect is immobilisation of the nitrogen due to a high C:N ratio in the mulch material (much carbon:little nitrogen). The nitrogen is then released back to the soil at a later stage. Without caution, the young plants can suffer from nitrogen and phosphorous deficiency in their early stages. This is not the case with nutritious and fresh legume/grass crop residue. This problem can be overcome with an extra dose of farmyard manure or nitrogen fertilisers at the time of planting.

### 3.2 Cover crops

The term cover crop is used in this manual for crops specifically grown to maintain soil fertility and productivity. They include green manures, cover crops and catch crops. A green manure crop is usually grown to maintain soil organic matter and to increase nitrogen availability. A cover crop is mainly grown to help retard soil erosion by keeping the ground covered with living vegetation and by having living roots holding the soil together. A catch crop is grown to retrieve available nutrients that are in the soil (during nitrogen flush) and prevents them from being leached during the short rains or when planting late.

One may also refer to cover and intercrop together. For example, an early bean crop can be used both as a cover crop and to produce beans for harvest. There are a number of considerations to be made when deciding which cover crop to use. These include:

- The type of plant and what it produces
- When and how the crop is planted, harvested, killed or incorporated into the soil.

Cover crops require more post harvest attention than other crops. A bean crop, for example, that is planted during the early rain may be ready for harvest during a moist period before the long rains. In this case, the beans can be dried in a simple drying crib. This technique ensures both good quality crop residue and a bean crop during a period when many farmers grow nothing but plough the land 2–3 times.

Potential cover crops suitable for north-western Tanzania include lablab (Lablab purpureus, earlier called Dolichos lablab), pigeon peas (Cajanus cajan), cowpeas (Vigna unguiculata), soya beans (Glycine max), common beans (Phaseolus vulgaris), sun hemp (Crotalaria ochroleuca and C. juncea), velvet beans (Mucuna pruriens) and others. The conditions vary greatly throughout the region thus there has to be specific local solutions to fit each farm.

Inter-cropping is a traditional practice but cover cropping is a new technique which requires more trials and demonstrations to answer unresolved questions about it. Therefore, it is not possible to give comprehensive recommendations in this manual on cover crops but to emphasise its importance and the need to be incorporate it in the dry land farming conservation tillage technique.

### 3.3 Mulch tillage technique

It is essential that the mulches are free from seeds, diseases and pests. It also important to ensure that mulches used do not regenerate. The residue of a previous crop such as maize or cotton may be slashed and left on the surface. Stubble from small grains like wheat, barley, and millet may also be used as residue.

Mulch ripping is a minimum tillage technique in which the land is ripped along each crop row. In most cases the fertilisers and seed are placed along the ripped line.

Tine planting, hoe planting into mulch and direct seeding are classed as zero tillage techniques. However, such techniques are hardly possible without sufficient mulch, due to weed infestation and increased risk of soil erosion. The requirement that 30% residue be left to cover the soil surface renders these tillage techniques less suitable in areas where the residue cover is burnt or used as animal feed.
An alternative conservation tillage system (which works well both with and without stubble mulch) is ridging using a ripper/ridger. This implement can work in quite heavy crop residue. However, it is always an advantage to chop long stalks to a maximum of 30 cm before using this implement, to avoid clogging and poor performance. Partly covered stubble (stubble mulch) both protects the soil and improves rainwater infiltration.

A method that prevents clogging of implements is to form lines of heavy crop residue with a stick at desired row width and allow the ripper to work along the lines that are free from trash (Figure 3.1).

![Organising crop residue in lines.](image)

Both ridging and split ridging are traditional methods which cover heavy trash gathered in the field or in the furrow bottoms. This technique can also be used to cover green manures. When ridging or weeding a field which has crop residue between ridges or rows, most of the chopped crop residue partly falls back as stubble mulch into the furrow bottom. One obstacle of leaving trash on the surface is that it is unsightly and it goes against good ploughing practices according to old schools of thought.

A crucial question, which needs urgent attention, is that of post-harvest grazing in the pastoralist/agropastoralist areas. This is common in many parts of Tanzania. The dilemma is whether cultivators that are brought into the area determine the fate of the pastoralists/agropastoralists, or to find solutions which benefit all groups. It is possible to improve the feeding efficiency substantially without damaging the land. It also possible to use better and simpler post-harvest practices and still leave some crop residue in the field. For example, by collecting nutritious leaves (pecking) when the crop reaches physiological maturity, and leaving the fibrous stems as mulch, little fodder is lost and mulch is provided to protect the soil. This technique is widely practised around Kilimanjaro.

Improved local transport is a key aspect in the collection of fodder like crop residue and for delivery of farmyard manure to the fields. Burning crop residue is a common practice that eases cultivation such as ploughing, but is strongly discouraged if a long-term build of soil productivity is to be achieved.

### 3.4 Weeding

Weeding is a major challenge in all crop production systems, but especially so in the initial years of conservation tillage. Conventional mouldboard ploughing is a common way of getting rid of early season weed infestation, since it is often carried out late after the onset of the rains when the young weeds have germinated. However, there are significant negative side effects of such practices. In semi-arid areas, the crop needs as much early rain as possible. To allow the early rains water the weeds only, is a waste of the scarce water resource. Further, weeds consume nutrients also. By abandoning the plough and planting directly at the onset of the rains (which is the benefit of early conservation tilling), weeds compete with the planted seeds. The need for early weeding is therefore more important here than in a conventional system—especially during the first
years after transition from conventional to conservation tillage. This is because ploughing (especially if weeds are not removed late in the season) basically turns into an efficient way of planting weed seed. Weeds flower and mature just like the main crop. When the plough turns the soil, weed seed are properly imbedded in the topsoil, ready to germinate at the first rains. Decades of ploughing and poor weed management lead to escalated weed infestation. This requires further intensive ploughing to keep pace with the growing weed problems. The soil progressively becomes addicted to ploughing such that ploughing increases weed problems, the remedy to which is ploughing, which further increases weed problems. Because of the weed triggering effect of ploughing (as is currently managed), much of the agricultural land in Tanzania is addicted to ploughing.

With conservation tillage, early weeding is needed, followed by 1–2 weeding rounds, at mid-season and before the weeds set seed. Proper mulching suppresses weeds. Maximising fertilisation and infiltration only in planting lines, thereby assures that weeds (between rows) suffer from lack of sufficient water and nutrients hence delays their growth. Progressively, weed problems decrease.

During the initial transition phase from conventional to conservation tillage, the weed problems may be so difficult that use of herbicides such as Round-up may be recommended. However, because conservation tillage means row planting in most cases, it enables the introduction of mechanised weeding. Animal drawn cultivators and ridgers can be very efficient and labour-saving ways of dealing with weed problems.

In summary, then, conservation tillage generally results in increased weed problems, especially during the initial transition from ploughing. Mulching, late season weeding, inter-cropping, use of herbicides and mechanised inter-row weeding are some of the ways to counter-balance this effect.

3.4.1 Transition to new production system

In many areas of Tanzania, the soil has been ruined from decades of conventional ploughing, resulting in severe ploughpans, serious weed infestation and soil erosion. This situation is normally the rule rather than exception in areas such as Arusha region, with a history of intensive disc ploughing. Under such circumstances it is no use introducing zero-tillage systems.

Instead, there is a need to pass through a transitional phase first. Experience shows that this phase may cover approximately 5 years and should achieve the following:

1. Remove ploughpans and alleviate soil compaction in general.
2. Build up organic matter content in the soil.
3. Reduce weed infestation.

The first step to take on seriously degraded cropland is sub-soiling. This breaks up the plough pans, assuring almost 100% infiltration of rainfall into the root zone and improved yields. It is often enough to sub-soil every third year or so, though the frequency depends on soil types and the degree of structural collapse of the soil.

During the first 2 years of the transition, deep chiselling or ripping of the entire crop field is normally required, to maintain high infiltration and establish an acceptable seedbed.

Make permanent planting lines (in the ripped lines) where all soil fertilisation is concentrated (manures and fertiliser). This progressively builds up good soil fertility in the root zone of the crop (and does not favour weed development). Introduce cover crops and practice intercropping to maximise soil cover, thereby enabling the build-up of organic matter in the topsoil.

Ensure good weed management for successful transition. Weed late to get rid of weeds before they set seed. This will prevent the multiplication of weeds.
With good infiltration guaranteed, soil fertility is restored through fertilisation and cover cropping. Weeds are suppressed, and after 5 years, it is possible to move from a sub-soiling/ripping system towards a minimum or zero tillage system (Brunner et al., 1999).

3.5 Transition to conservation tillage: Step-by-step experience in Babati region

It has been clearly demonstrated that modern farming techniques, like conservation tillage, if properly applied, make it possible to maintain close to virgin soil quality of cultivated land even among smallholder farmers in semi-arid areas in sub-Saharan Africa. However, until recently, the technique has been unknown in most of Tanzania except for the large-scale commercial farming sector. Therefore, it has been necessary to apply a step-by-step approach, starting with availability of the technique, adaptation to the local conditions and to create awareness in the farming population.

The 1995 findings in Babati region showed that restoration of exhausted and compacted soils to virgin quality was a highly desired feature by most farmers, though lacking in the technical know-how necessary to achieve this task.

Since ploughing was found to be a main cause of the low productivity, the entry point was to reduce the negative effects of ploughing. In this case, the ploughpan caused the prevailing drought sensitive and low yielding cropping systems. Opening up the compacted soils through deep tillage was selected as a starting point for restoring soils to virgin quality and to reduce soil moisture losses. For animal drawn techniques the new tillage implements developed in Zambia were chosen. These were used in a series of on-farm demonstration trials.

The process of selecting the improved animal draught power technique involved many meetings and training sessions with extension staff and farmers for whom this was a new approach. The new approach was called the dry land farming technique, whose aim was to minimise the effects of the prevailing droughts. Conservation tillage was an important component of the dryland farming approach. It is believed that the introduction of an animal drawn conservation tillage technique could be adopted relatively faster if attractive extension messages, proper training, sufficient resources and inputs were available.

As expected, farmers would not discard their ploughs immediately. In the Babati case, the first step taken was to reduce the damage of ploughing by letting the farmers decide on the best tillage options based on their own experience. This was the main reason for avoiding rigid recommendations and instead allowing farmers to experiment for themselves.

Key questions in conservation tillage are maintenance and development of soil aggregates, macro-pores and rainwater infiltration. These factors play major roles in rainwater and soil fertility management and are essential in productive farming in semi-arid areas with average rainfall below 800 mm/year.

3.5.1 Extension message for transition to conservation tillage

The initial recommendations for a transition from plough driven tillage to conservation tillage were:

- To break the ploughpan (by sub-soiling, ripping) to enhance the entry of rain water and roots into the soil
- To promote ox-drawn ripper/ridger as the alternative to the ox plough both for primary and secondary tillage (ridging, planting, weeding)
- Implement modifications to the soil and water conservation measures practised to fit the dryland farming-conservation tillage technique
- Farmyard manure application at the planting station to improve water holding capacity, structure and fertility of the soils
- To harvest and store the short rains in the soil to supplement the soil moisture during the long rains
• Use a combination of farmyard manure/Minjingu rock phosphate as an effective and low cost manure particularly on the acid soils which are prevalent in the programme area.
• Promotion of improved crop husbandry practices such as crop rotation, improved seeds, inter-cropping and cover crops to be strengthened.
• Introduction of multiple cropping in relation to rain water harvesting; (for example by growing a bean crop after the rains on residual moisture only).
• Introduction of stubble mulching techniques.
• Promoting of multiple cropping together with improved post-harvest practices (such as an early bean crop before the maize).
• Finding alternatives to post-harvest grazing.
• Discouraging burning of crop residue.
• Ensuring that mechanisation/tillage and soil conservation work jointly as one team.

These initial recommendations from 1995/96 proved correct and good progress was made in transition to conservation tillage.

Sub-soiling in the first year of transition resulted in a tripling of maize yields. This boosted the morale of farmers and extension workers in the region. The second season showed that crops perform well with conservation tillage even in severe drought conditions. During droughts, farmers either harvested nothing on the ploughed fields, or obtained a good yield where ripping/sub-soiling was practised. The third season was the 1997/98 El Niño phenomenon, which brought 2,500 mm of total rainfall. This heavy rainfall almost ruined the conservation tillage trials. The fourth season was another dry one combined with heavy army worm infestation where conservation tillage performed well.

Experience with farmers showed that the recommendations of 1995 are still relevant 5 years later. Currently (year 2000), it is merely a question of refining the technique, mulching and fertility issues. More information on possible refinements that can be done to integrate conservation tillage with soil and water conservation is given later in this chapter.

### Summary of transition to conservation tillage in Babati

Demonstrations on farmers’ fields in Babati District since 1995 showed that it was possible to double and even triple the maize yield just by breaking the ploughpan to enable water and roots to penetrate into the soil. Combining sub-soiling with simple improvements in crop husbandry and timing of operation can further double the production compared to the traditional ploughing-only system. Similar results were experienced with the other main crops in pure stands or with intercropping.

### 3.5.2 Integrating fertiliser use

Crops suffering from frequent water stress respond poorly to fertilisers, while the situation is opposite when this constraint is eliminated. This means that simple tillage improvements can open up the potential for substantial increases in both production and productivity.

Rock phosphate from Minjingu Mine, Babati District is one of the best rock phosphate deposits in the world (30% P₂O₅ (phosphate) and 40% CaO (calcium oxide)). Trials have shown great response to this fertiliser particularly in combination with farmyard manure on the dominating acid soils (Table 3.2). The average result from 8 farm trial sites in Babati District for 3 years 1996/97–1998/99 are given in Table 3.2.
Table 3.2: Rock phosphate trials in Babati District, 1996/97-1998/99

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grain/kg ha</th>
<th>Index</th>
<th>Stover/kg ha</th>
<th>Index</th>
<th>Biomass/kg ha</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1,813</td>
<td>100</td>
<td>2,063</td>
<td>100</td>
<td>3,876</td>
<td>100</td>
</tr>
<tr>
<td>Rock phosphate</td>
<td>2,967</td>
<td>164</td>
<td>3,608</td>
<td>175</td>
<td>6,575</td>
<td>170</td>
</tr>
<tr>
<td>Farmyard manure</td>
<td>2,872</td>
<td>158</td>
<td>3,793</td>
<td>184</td>
<td>6,664</td>
<td>172</td>
</tr>
<tr>
<td>Farmyard manure + rock phosphate</td>
<td>3,481</td>
<td>192</td>
<td>4,233</td>
<td>205</td>
<td>7,714</td>
<td>199</td>
</tr>
</tbody>
</table>

More work is needed to assess the economics of Minjingu rock phosphate.

3.5.3 Further step-by-step issues in conservation tillage

An important target is to develop and promote cropping systems that cope well with short drought periods of 4 weeks with little or no rain. Many of the suggested supporting activities are dependent on improved transport facilities and therefore it is essential that the manufacturing and supply of ox/donkey carts be given priority in the programme area too.

The crop mixture and cropping pattern should be one that supports both crop yield and biomass production and maintains soil fertility.

The above options should consider farm layout, village land use plans, and agronomic practices in relation to the local conditions.

Organic farming methods, which restrict chemicals and promote environmentally sound production methods are easily included in the conservation tillage concept.

The commercial farming sector in many parts of north-western Tanzania has already introduced sub-soiling successfully as a standard operation in upland cultivation. Tractor owners who provide shallow disc-ploughing services to smallscale farmers are discontented because the tractor drawn conservation tillage technique might jeopardise their business. Most of the tractors are in poor condition hence are unable to pull a ripper or a cultivator. The results obtained with the ox-drawn conservation tillage technique are very encouraging and demonstrate that a technique superior to ox ploughing is available.

3.6 Integrating soil and water conservation in conservation tillage

3.6.1 Linking soil and water conservation to conservation tillage

Soil and water conservation covers a wide spectrum of interventions:

- Scale: catchments to individual fields
- Land type: forest, rangeland, pasture and cropped land
- Land tenure: communal to individual holdings
- Enterprises: animal husbandry and crop husbandry
- Sources of erosion: ranging from headlands to storm drains to waterways
- Actors: from pastoralists to cultivators, and from communities to farmer groups and to individual farmers.

In this manual soil and water conservation is discussed in relation to conservation tillage with reference to individual farmers on their cropped land. A broad concept of land management is applied, where conservation tillage and soil and water conservation are dealt with as complementary fields of intervention that often go hand in hand. The previous discussions (in this manual) on the water balance in rainfed farming, point in favour of including soil and water conservation in rainwater management efforts and to look more into the totality of how rainfall is used for crop production.
Tillage has been overlooked in the common extension services messages on soil and water conservation. The common technique of ploughing for example is taken for granted and efforts are concentrated on conserving the ploughed land in the semi-arid areas. No doubt, better results would be achieved if soil and water conservation interventions were derived from more appropriate tillage practices. This weakness has recently been recognised and there are developments underway in to combine proper tillage with well-designed soil and water conservation measures. This includes better crop husbandry practices such as application of fertilisers (both organic and chemical), crop rotations, crop coverage, inter-cropping, cover crops, mulch and weeding.

A unanimous conclusion from farmers who tried the ripper/ridger technique is the non-existence of runoff from their fields and they have evidence that more rainwater infiltrates soil compared to infiltration with the ploughing-only technique.

Animal draught power using conservation tillage techniques can be combined with soil and water conservation. A technique suggested here is based on the well-established ox-drawn ridging technique used in Zimbabwe, which is designed by combining ploughing and ridging with a standard ridger. Using a plough with a ridger, contour bunds similar to the conventional *fanya chini* can be established very efficiently (using little labour time). This type of tillage is not as efficient as ridging with the ripper/ridger. Using conservation tillage for soil and water conservation thus adds a more secure and efficient system.

In preparation of a conservation tillage manual, it is important to aim towards the options that deliver a high level of efficiency.

### 3.6.2 Rainwater utilisation efficiency

The question of how well rainfall is utilised to grow a crop is an important issue in dry land farming. This ought to be more pronounced in the soil and water conservation concept as great improvements can be achieved through better tillage practices.

Figure 3.2 shows both rainfall data and the common planting time for the Kilima maize variety in the Babati area, and how much rain is required for a good crop. With the current ploughing technique, the option is to plant in early February to ensure availability of sufficient moisture to the crop. The rainfall between October and January is wasted, as far as the crops are concerned (but used instead by the weeds). The weeds have to be controlled by 2–3 ploughing/weeding operations.

![Rainfall data from Babati Town.](image)
With conservation tillage, the early rains are harvested and stored in the soil. This opens opportunities for early planting with high yielding crops, and even multiple cropping. A substantial amount of the rain is utilised fully for crop production, resulting in both increased cropping and food security. The situation is similar in other semi-arid parts of Tanzania.

The LAMP experience in Babati has shown that rainwater utilization efficiency can be improved along with soil conservation measures on ploughed land. The situation is further improved with conservation tillage techniques such as sub-soiling and ripping. The most beneficial is the combination of conservation tillage and soil and water conservation.

In discussing rainwater utilization efficiency in this manual reference is made in terms of yield/ha per mm of rain. During the 1980s the maize yield in Babati District was approximately 1.50 kg/ha per mm rain. With conservation tillage, it was possible to exceed this amount by 3–4 times. An exemplary performance was of a Maasai woman farmer who harvested 3,750 kg maize per hectare from 260 mm rain with the ripping technique. This is equivalent to 14.4 kg/ha per mm rain!

Usually, the maize crop performs poorly with the traditional ploughing technique when rainfall is below 450 mm, in the semi-arid north-western zone of Tanzania. Farmers who ploughed and used soil conservation measures obtained little yield at the lower bunds during dry years, while those who used conservation tillage got a normal crop. The best yields were from those with a combination of conservation tillage and soil and water conservation.

Under drought conditions, it is difficult to make sound comparisons, because of an almost complete crop failure for the ploughing technique and normal crop yields for the conservation tillage. Since irregular and heavy rain is a common feature in semi-arid areas, it is evident that rainwater utilization efficiency must be given highest priority. Impressive yields are achieved with better rainwater management techniques through better tillage practices. The possibilities of multiple cropping deserve more attention.

Another overlooked factor is poor aeration in compacted soils and waterlogging. Even where good rains occur, crop yields can increase substantially by allowing air into the soil. Lack of air in the soil is particularly a problem on heavier soils such as the black cotton soils (Vertisols) but the dominating loamy soils respond very positively to opening up of the structure using conservation tillage. Ridging is both an aeration and water harvesting option in relation to animal drawn conservation tillage, which improves rainwater utilization efficiency. Figure 3.3 shows a comparison between ploughing and sub-soiling of a maize field in Simanjiro District.

![Figure 3.3](image)

**Figure 3.3** Comparison between ploughing and sub-soiling of a maize field in Simanjiro District after a seasonal rainfall of 26 mm rain (July-June).
The field to the left in Figure 3.3 was disc ploughed, and the one to the right was sub-soiled (to 35–40 cm depth) by the same tractor. Both fields were planted in the same week with the same maize variety. The ploughed field failed completely while the sub-soiled field yielded almost 15 bags/acre (3,375 kg/ha, or 12.5 kg/ha per mm rain). No fertiliser was used in both fields. The rain had stopped by the time this photo was taken, but the sub-soiled crop continued to grow vigorously for 6 weeks from the harvested rainwater during the season. No doubt, this was another convincing example of the potential of dry land farming using conservation tillage on a farmer’s field.

3.6.3 The choice of technique

Distinguish between production systems

When considering the animal drawn conservation tillage technique it is important to distinguish between:

- Flexible and permanent cultivation systems
- Flat land cultivation and ridge cultivation
- Combinations of the above.

Other factors to take into consideration are the differences in rainfall distribution, desired crops and planting time and the use of crop residue. These include:

- Dry planting before the rains (short and/or long rains)
- Planting in the early rains (short and/or long rains)
- Planting in the long rains only
- Harvesting the rainwater in the short rains and using it to supplement the long rains
- Single-cropping and/or inter-cropping
- Weeding (by hand/mechanised, herbicides, mulch or cover crops)
- Use of residual moisture after the rains to have an additional crop like beans.

It is fairly complicated to discuss all alternatives available in this manual and therefore recommendations for the dominant farming conditions in semi-arid areas of north-western Tanzania (most of which are relevant for other areas in Tanzania as well) will be made. These include:

- Semi-arid conditions
- Farmers decision based on minimum risk strategy
- Low crop yields
- High cropping insecurity
- Inadequate soil moisture
- Poor rainfall utilisation rate
- Heavy run-off
- Rapid deterioration of soils and soil fertility
- Heavy weed infestation (grass weeds)
- Agropastoralist mode of production
- Post-harvest grazing (limited amount of crop residue)
- Shortages of labour, farm power and farm transport during critical periods
- Limited availability of essential inputs
- Poor marketing.

Animal drawn conservation tillage would be a non-starter if the above factors are ignored. Table 3.3 is a simple matrix of good guidelines on where to concentrate development efforts.
Table 3.3 Matrix on cropping systems in the LAMP area (Babati, Kiteto, Simanjiro Districts)

<table>
<thead>
<tr>
<th></th>
<th>Traditional approach</th>
<th>Conservation tillage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ploughing with no SWC</td>
<td>Ploughing with SWC</td>
</tr>
<tr>
<td>In use (farmers)</td>
<td>Dominates heavily</td>
<td>Few</td>
</tr>
<tr>
<td>Crop yield</td>
<td>Low</td>
<td>Good</td>
</tr>
<tr>
<td>Cropping security</td>
<td>Low</td>
<td>Good</td>
</tr>
<tr>
<td>Runoff level/erosion</td>
<td>High</td>
<td>Low, but controlled</td>
</tr>
<tr>
<td>Sustainability</td>
<td>Low</td>
<td>Good</td>
</tr>
<tr>
<td>Weeding</td>
<td>Hand</td>
<td>Hand</td>
</tr>
<tr>
<td>Construction of SWC</td>
<td>Hand</td>
<td>Hand</td>
</tr>
<tr>
<td>Labour constraints</td>
<td>Medium high</td>
<td>High</td>
</tr>
<tr>
<td>Implement cost; relation</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td>Productivity, yield/man hr</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Suitability:</td>
<td>- Homestead</td>
<td>Suitable</td>
</tr>
<tr>
<td></td>
<td>- Farmland</td>
<td>Unsuitable</td>
</tr>
<tr>
<td>Ranking (appropriateness)</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

SWC = soil and water conservation.

The traditional soil and water conservation recommendations in the LAMP districts are based on hand-dug and grass-stabilised contour bunds, combined with zero grazing (cut-and-carry). This makes this technique hardly suitable for the large area of farmlands, which are far away and exposed to post-harvest grazing. However, it is suitable for the small homestead gardens where the grass on the contour bunds can be supervised.

Repairing contour bunds manually every year, after being damaged by livestock, is a hard task for most farmers. However, if the repairs are mechanised using the means available to most smallscale farmers in the region, it becomes an easy task, which allows for more flexible and appropriate soil and water conservation techniques for specific areas and conditions. An alternative is to reduce the number of free grazing livestock. However, the social, cultural, technical and economic implications of promoting the zero-grazing-only technique in the agropastoral region in north-western Tanzania is not feasible. Meat, milk, animal draught power, farmyard manure and traditional values are important components in the prevailing farming/livestock systems and it is essential to find a good but acceptable production mix of securing fodder for the livestock.

3.6.4 The proposed choice of technique

The discussion above suggests that it is more appropriate to aim at a permanent ridging system based on the ripper/ridger along the contours. When established, the only tillage necessary would be hilling up the old ridge, planting and weeding. The old crop roots are left intact, to ensure optimum soil conditions in the ridge. Tying the ridges is also highly recommended for maximum rainwater utilization. Inter-cropping and cover crops are essential in this system. Occasional split ridging is required to control noxious weeds.

The other conclusion is to advocate for the ripper/ridger provided that tillage is made along the contour. There is no argument about the importance of the various soil and water conservation techniques, but farmers can initiate ripping and include these techniques later, if required. This is a better option to ploughing without soil and water conservation.

An important factor in the process of change is flexibility. Most farmers prefer trying new techniques gradually before fully accepting them and are hesitant to follow rigid recommendations. A variety of options is more acceptable to them. The ripper/ridger gives the flexibility required.

Ridging is rarely practised nowadays, except where sweet potato is grown. Re-introduction of ridging must
be a gradual process. Elderly people know the technique well, but it is new for most young people. A transition period must be anticipated and extensive extension services, training and marketing efforts are required. Whatever the speed of change, the use of the ripper/ridger for tillage, planting and weeding constitutes a great step forward with or without permanent ridges compared to the ploughing-only technique.

### 3.6.5 Soil and water conservation measures

Most of land in the country is undulating. Only a few fields have slopes above 15% (1 m increase per 6.7 m). Consequently, most of the land can be protected by good conservation tillage practices based on the ripper/ridger using the common soil conservation technique in laying out contour bunds. Chapter 7 gives more details on how to achieve this task. Following, is a discussion on the basic conditions for different field slopes:

1–2% slope: Ridge across the slope following the contour line. No need for specific soil conservation structures.

2–7% slope: Construct contour bunds 30 m apart using the ripper/ridger. Start ridging along the upper contour bund on even slopes. Observe the need for eventual storm drains. On uneven slopes follow a master ridge (see Chapter 7).

7–15% slope: Construct bigger contour bunds 20 m apart with a combination of ripper/ridger and ox plough. The rest remains the same as for 2–7%.

It is advisable to stabilise the contour bunds by planting grass on them, or allowing weeds to grow. If the fields are exposed to heavy post-harvest grazing, they should be rebuilt every year. Usually, the old bunds are followed and hilled up. This can be a simple and easy job, especially if mechanised with a ripper/ridger. Planting the bunds with vetiver grass reduces the grazing damage.

The safety and efficiency in relation to rainwater and soil management is greatly improved by tying the ridges. Chopped trash in the furrow bottom improves water infiltration and reduces eventual runoff along the ridges.

An alternative to bunds is grass strips of suitable grasses like vetiver grass. These are planted in a deep ripper furrow. They are best hilled-up by the normal ridging operation with the ripper/ridger, and prove to be good markers for the layout of tillage system.

The feasibility of the hand-dug and grass-stabilised *fanya juu* and/or *fanya chini* structures in combination with zero grazing ought to be seriously discussed in semi-arid agropastoralist areas exposed to post-harvest grazing. Considerations that must be made include whether the structures remain permanent, or are be rebuilt every year. In addition, consider whether to adopt the technique to the prevailing conditions or to impose new rules for the new technique. The conservation tillage technique allows flexibility in these respects. The research programme at Sokoine University of Agriculture on rainwater harvesting of runoff water for crop production concluded that this technique (*grass-stabilised fanya juu/fanya chini* structures) works under specific conditions, is costly and that almost the same results are achieved with a simple dry land farming/conservation tillage technique such as applied in LAMP/SCAPA.

### 3.7 The animal draught power development trend

Most animal draught power development efforts in eastern Africa are centred on the plough. Hardly any other tillage implements are promoted and made available to the farmers in any real sense, except in specific projects. What is expected in the field of appropriate tillage technique promotion? It appears a serious contradiction that an outdated ploughing technique developed in temperate areas is still promoted as the best tillage option for semi-arid Tanzania in particular, and Africa in general.

The pioneering work on ox-drawn ripping and sub-soiling in Zambia is unique and highly commendable. It has opened up a new avenue for an increase in animal draught power cropping systems development.
The productivity of land in semi-arid Africa is decreasing at an alarming rate. All signs justify an urgent need to change farming techniques. It is essential to make farmers aware of the reasons for the problems and to involve them fully in the development of required improvements. Essential as it is, change in tillage technique should not be initiated if alternatives and inputs required are not available.

The classical approach of concentrating on ploughing in the animal draught power training process of farmers and oxen has proved that it effectively excludes other ox-mechanised tillage options despite all good intentions in animal draught power training manuals.

For example, ox-drawn weeders in Tanzania weed less than 0.03% of the land ploughed by oxen today despite 30 years of extension efforts. It is a wonder that ox-mechanised weeding has been promoted all this time. The same is observed on ox-ridging, an excellent traditional tillage practice in semi-arid areas, which has been discarded. The situation is no better in planting techniques. Plough planting dominates and as a result any mechanised weeding is difficult due to irregular row spacing.

If ploughing is the only technique promoted, ploughing and hand hoeing remain the only available options for primary and secondary tillage. Ox ploughing followed by hand weeding is a classical example of a sub-standard technology. A serious implication of poorly designed smallholder mechanisation systems is that the traditional female duties are effectively excluded from most of the animal draught power development agenda today. It is evident that there is a good case for re-orienting the animal draught power training system away from ploughing and instead centre it on desired conservation tillage options. No doubt, there is a need for a radical change based on a well-designed and attractive message.

### 3.8 The spread of conservation tillage in Tanzania

Large-scale commercial farming based on the conservation tillage approach is well established in South Africa, Zimbabwe and Zambia and is getting established in Tanzania and Kenya.

Countries such as Zimbabwe, Zambia, Lesotho and South Africa are promoting conservation tillage at the small-scale farming level. Conservation tillage in the modern context has just begun in the smallscale farming sector of Tanzania. Some isolated areas like Mama Isara in Mbulu District, Bulongwa, Kilimanjaro and Tabora, have practised the conservation tillage technique by hand for hundreds of years, though it has not spread outside these confined areas.

Animal drawn CT technique is new in Tanzania, and has so far been tested in the Dry Land Farming Programme in LAMP/SCAPA and in District Programmes in Mwanza region with good results.

### 3.9 Marketing the conservation tillage technique

As mentioned earlier, animal drawn conservation tillage cannot start without (i) interested, motivated and skilled farmers, (ii) good quality implements at affordable prices and (iii) properly trained draught animals. There will be a slow, risky and costly implementation phase, with small chances of success, if any of these inputs are not available.

A well-know farming systems specialist (Dr M. Collinson) stated in 1977 in the Commonwealth Rural Technology Meeting, in Arusha, that the message was the key issue when introducing a new farming technique, even for smallscale farmers. If the message is attractive, sound and within reach, it spreads and is adopted with or without the extension service. However, the speed of adoption is greatly enhanced with properly trained, skilled and motivated extension staff, but they are not necessarily a precondition for introduction of a new technique.

Skilled commercial marketing can perform much better than an ineffective extension system provided there is a good demand for the message and the linked products. The combination of a weak extension and a poor
or non-existent marketing system is not a good starting point for a rapid introduction of a highly required conservation tillage technique. Unfortunately, the private marketing agents and the extension service are not used to working together and it is essential to initiate good co-operation.

It is a well known fact that skilled and motivated extension workers and entrepreneurs can do an exemplary job if allowed enough resources provided they have the right message they believe in, skill and/or product(s) to market.

Experience in north-western Tanzania shows that good knowledge and skills among extension staff in promoting and applying the animal drawn conservation tillage technique is the crucial starting point for introducing the desired technique. For example, each extension worker must be knowledgeable and skilled in training draught animals and in using the implements in a professional way. They must be confident and skilled in demonstrating the technique in a convincing way to farmers (training of trainers). Then follows training of the selected contact farmers who try, develop and demonstrate the technique to their fellow farmers.

The intention of this manual is to give the extension staff and the lead farmers the required skill to pursue the conservation tillage technique task in a conducive and professional way. Most farmers are convinced by a real professional extension worker when new farming techniques are being promoted. The extension workers should also apply the technique on their own farms, as demonstration farmers.

The next step is ensuring availability of required inputs, hence the marketing promotion should start as early as possible. Farmers are weary of trying new techniques, which never come to the market or are too costly. Another crucial aspect is training of the sales agents in promoting the technique and on how to be dynamic sales agents. The common system whereby customers are waited for is a too slow and inefficient marketing system. Instead, the marketing agents should approach the farmers and be more sales oriented.

With the above base in place, and the technique locally adopted, works well and is accepted by the lead farmers and their fellow farmers then comes the next step. This is usually an extension/marketing campaign in selected areas to create awareness, interests, motivation and possibilities to encourage adoption of the new technique. The number one priority at the first campaign phase is to get a critical mass of early adopters in some areas, which can spearhead a dynamic and self-generating development of private initiatives.

It is appropriate to apply a participatory extension approach, extend awareness and to assess interest and constraints and how to adapt to farmers’ or market demands. Be careful not to push for significant changes of farming systems rapidly with farming communities guided by a basic minimum risk strategy, without a sound foundation of the risks involved. It is necessary to prove to the farming community that a novel technique will improve cropping/food/fodder security, to draw their attention. A lot of interest is generated if the technique is demonstrated on farmers’ fields to show what can be achieved with simple means even under adverse conditions. Furthermore, flexibility is a key aspect to satisfy cautious farmers’ resistance to changes. Rigid recommendations are bound to meet with resistance.

The importance of the marketing phase cannot be over-emphasised. This new technology attempts to abandon a technique that has been recommended and promoted for almost a century in Tanzania, and elsewhere in Africa, by both research and extension and the international agencies. It must be anticipated that it will take time for success to be realised, and that it will be accepted because it is the right message!
4 Regional outlook

Conservation tillage is not a new concept. Manual pitting systems, like the *matengo* pits in Tanzania and the *zai* pits in Burkina Faso, are traditional conservation tillage techniques whose aim was the long-term build-up of soil productivity. In the United States, no-till experiments started in the 1930s, using chisel ploughs, in an attempt to reduce the damage caused by the famous dust bowl wind erosion. As far back as 1943, the famous book *Plowman’s folly* by Edward Faulkner was published. This book questioned the wisdom of ploughing and stated “No one has ever advanced a scientific reason for plowing”. Mechanised commercial farming using no-till was first developed in the early 1960s, with successful results in conserving soil and water, saving time, labour, fuel and often producing higher crop yields. Today, some 20% of the cropland in the USA is under zero-tillage and more than 50% is under some type of conservation tillage.

Brazil has experienced large-scale expansion and adoption among small-scale farmers of zero-tillage systems over the last three decades from approximately 1000 ha in the early 1970s to an estimated 8.4 million hectares in 1998 (Derpsch, 1998). A lot of research and development is going on in the use of cover crops and crop rotations, and the reduction in the use of fertiliser and herbicide. The adoption of zero-till covers a broad range of soils with clay contents ranging from 10% to 70%. A major goal in the conservation tillage efforts in Brazil is to restore a virgin or natural soil quality after decades of conventional ploughing, which has lead to a decline in soil fertility and destruction of soil structure.

In Africa, conservation tillage research has been conducted since the late 1960s, for example in Ghana. At the International Institute for Tropical Agriculture (IITA) in Nigeria, there has been extensive research on zero-tillage systems (Lal, 1973). Conservation tillage systems have been tested over the last 20 years in several countries in sub-Saharan Africa, including Angola, Benin, Côte d’Ivoire, Ghana, Kenya, Mozambique, Niger, South Africa, Tanzania, Zambia and Zimbabwe. Commercial farmers have adopted chisel ploughing and zero tillage systems for large scale mechanised production of cereals in Tanzania and Zimbabwe. In Zimbabwe, for example, the Hinton Estate (the largest commercial farm in the country) has used conservation tillage methods for the last decade. Low production and highly eroded cropland was converted to extremely high production with maize yields of 10 tonnes (t)/ha (Oldreive, 1993). There are also many examples of successful conservation tillage practices among small-scale farmers in eastern and Southern Africa, where crop yields have increased through the conservation of soil, water and nutrients and/or draught power needs (Elwell, 1993; Oldreive, 1993; Vogel et al., 1994). A lot of work has been done on how to develop conservation tillage in partnership with small-scale farmers in Zimbabwe (Chuma and Hagmann, 1995). Similarly, in Zimbabwe, no-till tied ridging and mulch ripping have been studied for almost 10 years, showing very high reduction in soil erosion and maintained or increased yields.

In Botswana, conservation tillage research has been going on since the early 1970s. Strip tillage systems have been developed on light soils, with good impact on crop yields in dry semi-arid areas. Efforts in Zambia by several actors over the last 10 years have resulted in conservation tillage (defined as conservation farming) being advocated as a national agricultural policy for development of the smallholder sector in the country. The Zambia National Farmers Union (ZNFU), through the Conservation Farming Unit, has been very successful in promoting zero-till conservation tillage systems for cash crops such as cotton in partnership with the private sector. The Smallholder Agricultural Mechanisation Promotions (SAMEP) programme, which started in 1986, has focused on the development of animal drawn conservation tillage implements and local manufacturing of implements (IMAG, 1999).

In South Africa, the Agricultural Research Council (ARC) has been conducting conservation tillage trials for over 20 years, and is now in the process of working on farm with smallholding farmers on various zero-till and animal drawn systems.

In Ethiopia, the dominant tillage implement is the *maresha* ard plough. To grow the national staple food, *teff* (*Eragrostis tef*), the crop fields are often ploughed 5–7 times to assure a fine seedbed for this small-grained
cereal. Ploughpans, wind and water erosion and the large labour and traction requirements (delaying timing of operations) have resulted in serious land degradation and reduced crop yields. Efforts are ongoing to develop and test conservation tillage attachments to the maresha to reduce the tillage requirements and improve infiltration of rainfall. This work is being carried out by the Ethiopian Agricultural Research Organization (EARO) in partnership with RELMA.

In Kenya, a conservation tillage initiative has recently been launched. It includes a series of on-farm trials to test several different conservation tillage methods using animal traction, in different agro-ecological zones.

These are just a few examples of past and ongoing regional experiences using conservation tillage. It shows that conservation tillage has been studied, tested and developed over a long time in all continents of the world, with high adoption in some countries such as Brazil and the USA. In sub-Saharan Africa, adoption among smallholder farmers has until now been relatively low. Several reasons for this have been identified such as the limited access to implements and the low capacity of extension service workers to train farmers in conservation tillage.

### 4.1 Some examples of experiences using conservation tillage in eastern and southern Africa

Table 4.1 shows a comparison between the effects of ploughing and conservation tillage on soil and rainwater losses per year under similar conditions.

<table>
<thead>
<tr>
<th>Tillage practice</th>
<th>Soil losses</th>
<th>Rain loss (%)</th>
<th>Loss N and P (TSh/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crop</td>
<td>t/ha</td>
<td>%</td>
</tr>
<tr>
<td>Ploughing</td>
<td>Cotton</td>
<td>75</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>maize</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Conservation tillage</td>
<td>cotton</td>
<td>3</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>maize</td>
<td>1</td>
<td>0.07</td>
</tr>
</tbody>
</table>

\( k = \text{nitrogen}; \ P = \text{phosphorus}. \\
Source: Ildreive. 1993

Soil losses usually involve the fertile topsoil. Consequently, the ploughing technique is highly wasteful and can be classified as mining the soil and the environment. The large reduction in soil loss though CT reduces the need for comprehensive soil and water conservation measures as the improved tillage technique almost eliminates runoff on most agricultural land.

The picture in Figure 4.1 shows maize grown under conservation tillage based on zero tillage in Zimbabwe. A planting furrow is opened through the crop residue mulch and the maize seed is planted in there in. Figure 4.2 shows the long-term (7 years) effects of different tillage practices at IITA, Nigeria. The crops involved are maize and soybeans; there is a great difference in favour of conservation tillage.

Figure 4.1 Maize under conservation tillage.
The poor crops in the middle are a result of continuous ploughing-only technique and the healthy ones are under CT (Figure 4.2); the plots received the same amount of fertilisers. The difference is caused by the tillage technique alone. This information is representative of large tracts of land in Africa and it is evident that maintaining virgin-quality soils is hardly possible where ploughing is the main tillage practice. However, CT opens up new avenues for practical and realistic approaches of implementing sustainable and productive farming systems in semi-arid areas. There are good indications that this conclusion is also relevant in humid areas.

If development of sustainable and highly productive cropping systems is a priority, it must be accompanied by a change from the old ploughing technique to conservation tillage.
5 Conservation tillage as part of integrated watershed management

Conservation tillage aims at reversing reduced infiltration, which is a persistent trend in many production systems. Reduced infiltration occurs due to compaction, crust formation and reduced water holding capacity resulting from the oxidation of organic materials (caused by excessive turning of the soil). From this perspective conservation tillage is a form of rainwater harvesting, where runoff is reduced to a minimum and soil water is stored in the root zone of the crop.

For semi-arid regions (which constitute almost 40% of the arable lands in sub-Saharan Africa) the crucial issue for rainfed agriculture is whether there is enough water to permit significant yield increases. When assessing this question it is useful to study the water balance in a rainfed semi-arid farming system.

5.1 Blue and green water flow

The water balance shows how rainfall is partitioned into different flow branches. On all scales—on a farmer’s field or in a river basin—the rainfall is partitioned into blue and green water flows. Blue water flow consists of the runoff branch of the water balance, supplying water as surface runoff (sheet, rill or gully flow) or subsurface drainage flow. Blue water is the water tapped for drinking from rivers, wells or lakes. Green water is the water that returns to the atmosphere as vapour. It is divided into an unproductive part, evaporation, and a productive part, plant transpiration. Productive green water is the proportion of rainfall that infiltrates into the soil and is taken up by the roots and passed through the leaves into the air. It has been shown in many trials that there is a linear relationship between productive green water flow and crop yield. Increased transpiration means increased food production.

Figure 5.1 illustrates a synthesis of observed water flows on a field in rainfed crop producing systems (Rockström et al., 1999). The total rainfall in Figure 5.1 is symbolised with $R = 100\%$. Blue water as surface runoff ($R_{off}$) is generally in the range of 10–25% on average (much higher for individual rain storms). This is due to inadequate infiltration caused by high intensity rainfall events, seal/crust formations, hardpans, and poor canopy and soil coverage. Non-productive green water as soil evaporation losses ($E_{soil}$) range is 30–50% higher for degraded lands and lower for productive land. The character of tropical rains with large volumes falling in a short period of time also leads to significant blue drainage flow ($D_{drain}$), even in dry lands, amounting to 10–30%. The higher figures are for more permeable lighter soils which have low organic matter content. This means that only 15–30% of the rainfall ($E_{crop}$) is directly used as productive green water flow as crop transpiration for biomass production. The level of transpiration is determined by the crop growth and the related grain yield.

Figure 5.1 General overview of rainfall partitioning into green (evaporation and transpiration) and blue (deep percolation and surface runoff) water flows in semi-arid tropical farms in sub-Saharan Africa. $R =$ rainfall, $R_{off} =$ runoff, $E_{soil} =$ soil evaporation, $E_{crop} =$ transpiration, $D_{drain} =$ deep percolation (adapted from Rockström et al., 1999).
A grain crop of 1,000 kg/ha requires about 100 mm of rainfall for transpiration. An annual rainfall of 500 mm means that 20% of the rainfall is used by the crop. The rest is lost through evaporation, runoff and drainage. A doubling of grain yield from 1,000 kg/ha to 2,000 kg/ha roughly requires a doubling of the available water for crop transpiration. In the above case it means that 40% of the rains are required for the necessary crop transpiration. If this demand cannot be met it is not possible to achieve this higher crop yield level. Transpiration can fall to as low as 5–10% for degraded cropping systems where crop yields are in the order of 1.5–3 bags/acre (500 kg/ha).

The analysis of rainfall losses in semi-arid areas indicates that water scarcity is not necessarily caused by low cumulative volumes of rainwater but rather by poor distribution of rainfall, large evaporative demand of the atmosphere and large losses in the water balance.

Generally speaking it is difficult to reduce evaporation from the soil or from plant surfaces. The top 5 cm of soil is particularly exposed to high losses. Soil evaporation gradually diminishes and is marginal at a depth of 10 cm and below. The dryland farming experience shows that the surface dries quickly whereas the soil can stay moist for months at a depth below 10 cm. This means that rain water that can percolate into the soil below this depth can be stored with small evaporation losses.

Light showers, which wet only the surface of the soil are more sensitive to evaporation losses in hot weather than heavier downpours, which enter deeper into the soil. It is essential to create conditions for speedy entrance of rains into the soil. As little water as possible should be left in the upper 5 cm of the soil.

When ploughing a soil (inverting), the moist lower part of the cut slice is brought up to the surface and gets exposed to heavy evaporation losses. This means that tillage is highly instrumental to increasing evaporation losses. However, appropriate tillage can also be used to minimise the water losses. Root depth and density determine the ability of a plant to absorb the soil water. These factors are crucial when managing drainage losses to a plant.

Soil structure and organic matter content are important factors for determining holding capacity of field water. Mulch reduces soil temperature and wind speed at surface level which is important for reducing surface evaporation losses. It also protects the soil from the impact of heavy rains and increases the amount of runoff water held by the soil.

Surface runoff losses are closely linked to the infiltration capacity of a soil. Surface crusts and hardpans severely restrict infiltration into a soil. The shape of the soil surface also determines the amount of water loss. Ridges along the contour harvest rainwater more efficiently than even flat land cultivation.

The experience in Babati shows clearly that it is possible to improve rainwater utilisation efficiency 3–4 times in farmers fields with simple conservation tillage techniques. The above speaks in favour of sound rainwater management as a pre-condition for increased sustainable production. Good rainwater management in semi-arid areas involves measures to:

- Ensure maximum rainwater infiltration and soil water storage capacity
- Minimise runoff
- Convert non-productive evaporation to productive transpiration
- Ensure deep and vigorous crop root systems for maximum absorption capacity of water and crop nutrients.

An important conclusion is that these recommendations must guide crop production including soil and water conservation and tillage. There is a large potential to increase crop yield and cropping security in semi-arid areas by improving soil and crop water management. For example, it is possible to store 4–6 weeks of water requirements in most soils for a maize crop provided that rainwater enters freely and roots suffer no hindrance as they grow downwards. This is a crucial factor when discussing crop security and land management. One complicating issue is that weeds also respond well to improved rainwater harvest practices and adequate weed control is necessary to prevent loss of benefits.
6 The effects of tillage on soils

6.1 General

The basic requirements for germination, emergence and growth of a plant are shown in Figure 6.1. In a natural state a wide variety of plants compete for the available requirements and only the species which grow well in that environment survive. The water, air and nutrients that the plants need are absorbed through their roots hence a well-developed root system is key to successful growth of plants.

Humanity has developed certain plants as crops for food, fodder and other purposes. To obtain good yields from these crops they are planted in controlled plant populations. The undesirable plants are regarded as weeds. These weeds compete with the desired crops for available space, light, water and nutrients. Crop production requires that the natural state of the soil be opened to allow ease of seedling emergence and good plant growth. Before a crop is planted suitable conditions have to be created in time for optimum and sustainable crop development.

6.2 Tillage

Tillage is, essentially, humanity’s interference in the natural soil conditions. It is defined as “the change of the physical condition (structure) of the soil by mechanically turning it over, shaping, loosening or mixing it to "optimise conditions" for crop seed germination, emergence and growth” (AETC, Zimbabwe, 1986 in the reference list). The term optimise conditions is highly controversial under tropical semi-arid conditions. What is regarded as optimal tillage can turn out to be highly detrimental to the soil in the long term. A tillage system based on short-term benefits is not sustainable and may indeed be a threat to future production.

Tillage is traditionally divided into two stages: primary and secondary. Primary tillage deals with the initial preparation of the whole layer of soil required for seed placement and seedling emergence. A suitable depth of soil is loosened for water storage and air circulation for purposes of seed germination and root development.

Secondary tillage involves the creation of a finer tilth required for germination and emergence of seeds. It is essential to establish good seed-soil contact so that seeds absorb moisture from the soil particles. The soil
above the seed must be loose enough to allow the shoots to penetrate the soil above and reach the surface. The soil below must be porous to allow deep root penetration (Figure 6.2). Further, secondary tillage operations may include weeding, which affects the top few centimetres of the cultivated soil surface.

**Figure 6.2.** Development of maize seed planted in a good seedbed.

In addition to the above definitions, the following terms are also commonly used:

- Traditional tillage
- Reduced tillage
- Minimum tillage
- Zero tillage.

The basic criteria for these options are the intensity of tillage. The controversial question on tillage is often the issue of degree: how much and how deep should tillage operations be and how much crop residue should be covered/incorporated. Most animal draught power training programmes in eastern and Southern Africa are based on the training manuals from Zimbabwe, and, since the mid-1980s, recommendations from this country take the lead in animal drawn tillage systems. A traditional approach to primary and secondary tillage centring on the mouldboard plough was followed.

Animal draught power tillage practices in use today include:

- Traditional flat land cultivation
- Traditional ridge cultivation
- Conservation tillage.

The word traditional, in this context, refers to a well-established and widely practised system. There have been many different traditional practices during the last 10–40 years dating back to when real traditional practice was used.

Traditional flat land cultivation includes:

- Primary tillage, which is essentially ploughing
- Secondary tillage, which involves harrowing, hand planting or ox-drawn planter and weeding by hand or by inter-row cultivator (plough planting and hand weeding dominates in Tanzania).

Traditional ridge cultivation includes:

- Primary tillage, which may have two alternatives, namely:
  1. Alternative 1 - ploughing then ridging with standard ridger or ridging by hand (hand ridging is the most dominant in Tanzania but popularity is decreasing rapidly due to heavy labour input)
2. Alternative 2 - split ridging with standard ridger
   • Secondary tillage: hand planting, weeding with standard ridger or by hand.

Conservation tillage includes:

• Primary tillage: sub-soiling with sub-soiler and/or ripping with ripper/ridger and/or ridging with ripper/ridger (more details in Chapter 2)
• Secondary tillage: planting and weeding with ripper/ridger.

The main differences between the above-mentioned tillage systems are the intensity and depth of tillage and degree of coverage of crop residue. In principle the traditional tillage approach is based on the belief that there is a benefit in changing the virgin quality of soil to other conditions deemed essential. In traditional tillage crop residues are thoroughly incorporated into the soil, taken away or burnt. The soil surface is cleared of any crop or weed residue to enable smooth primary and secondary operations. The long-term effects of using the traditional tillage systems listed have been overlooked to a large extent.

The basic aim of conservation tillage is to maintain and/or restore the virgin quality of land. As much crop residue as possible should be left on the soil surface. The key issue in conservation tillage is sustainability and safeguarding a high production level on a long-term basis. It is apparent that these two systems are hardly compatible and a farmer must make a decision on which one to follow.

6.3 The soil structure

Soil consists of particles of mineral matter (that ranges in size from microscopic clay particles to stone and gravel), organic matter, air and water. Soils are classified as sandy, loams and clay soils, but there are combinations of these soils. Loams dominate the cultivated land in the semi-arid parts of north-western Tanzania. The organic matter and clay particles glue the soil particles together to larger granular aggregates. The soil structure depends on the aggregate sizes and their arrangement and strength.

Virgin soils have a higher organic matter content than cultivated land. The average organic matter content on the latter in Babati District is 2.21%, and consists of decaying plant tissues, animals, micro-organisms and manures. It represents a balance between added plant residue including old roots and destructive decomposition and erosion. The soil organic matter in the topsoil is highly influential in:

• Soil fertility
• Density and soil aggregate sizes and strength
• Water infiltration rate and water holding capacity
• Retention and release of plant nutrients
• Biological activities and rooting depth
• Resistance to surface crust and hardpan formations and erosion.

The organic matter level in the soils of Babati District is classified as low to very low. The situation is hardly better in other parts of semi-arid Tanzania. The thickness of the topsoil varies according to precipitation and vegetation. In the semi-arid areas, it is common to find cultivated land with soil organic matter content below 1%. At this level, most soils have changed their original properties, and become largely unproductive.

Figure 6.3 illustrates the differences in aggregate structure formation of sand and clay soils. The loams are in between though not as cohesive as clay.

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1 72 samples from throughout the district.
Figure 6.3  Soil structure (after Elwell, 1989).

Comments on Figure 6.3:
The soil aggregates in clay soils (a) do not collapse when wet. Large gaps remain between them. Soil in this condition has good drainage, high water infiltration capacity, good moisture and nutrient holding capacity and is easier to work. However, if the large aggregates collapse into very small units (b), the soil immediately slumps into a dense mass with properties that are opposite to the above descriptions.

Parallel circumstances occur in sandy soils. The soil is in its best condition when humus from organic matter separates the sand grains (c). Humus holds water up to 20 times its weight. When humus is absent (d) the soil forms a dense mass and begins to exhibit undesirable properties. If the sand grains are of similar sizes they may create hardpans restricting both water flow and crop root development.

When soils have a structure, such as (b) and (d), they have a low resistance to the impact forces of raindrops. During heavy rains, the surface structure disintegrates further, restricting infiltration and causing splashing, runoff and erosion. In more serious cases a seal is formed that closes the soil completely. Such a seal turns into a crust when dry. The thickness of the crust may vary from a few millimetres to a few centimetres. The hardness of the crust increases with the level of the deterioration of the soil.

Fine sands, silty soils, soils that are low in organic matter and montmorillonite clay soils (e.g. black cotton soil) are highly susceptible to erosion. Concrete hard crusts and/or ploughpans are common in the loams within the programme area. The aggregate diameter is a good indicator of the quality of soils after exposure to tillage and cultivation. Table 6.1 shows a comparison between a soil common in the programme area (clay loam) in a virgin stage, and under cultivation.

Dry sieving means that the aggregate distribution was analysed in a dry soil. Wet sieving is analysis of a soil immersed in water. The latter condition is similar to what happens in a saturated soil. Table 6.1 below shows that cultivation compacts a virgin soil. The mean weight diameter reduced from 8.85 mm to 4.30 mm in a dry soil.

Wet sieving reduced the diameter from 8.85 mm to 4.56 mm in the virgin soil and from 4.30 mm to 1.16 mm in the cultivated soil. This indicates the degree of instability of the various aggregates under the slacking effect of immersion in water. The influence of cultivation generally is to reduce the water stability of soil.
aggregates and hence render the soil more vulnerable to compaction, splashing, crusting and erosion processes. It is evident that the desired properties of a soil exist in its virgin state and these deteriorate quickly when exposed to cultivation.

Table 6.1  Examples of aggregate distribution (B) in a clay loam soil

<table>
<thead>
<tr>
<th>Aggregate diameter range (mm)</th>
<th>Virgin soil</th>
<th>Cultivated soil</th>
<th>Virgin soil</th>
<th>Cultivated soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dry sieving (%)</td>
<td>Wet sieving (%)</td>
<td>Dry sieving (%)</td>
<td>Wet sieving (%)</td>
</tr>
<tr>
<td>0.0–0.5</td>
<td>10</td>
<td>25</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>0.5–1.0</td>
<td>10</td>
<td>25</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>1–2</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>2.5</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>5–10</td>
<td>20</td>
<td>10</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>10–20</td>
<td>20</td>
<td>7</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>20–50</td>
<td>10</td>
<td>3</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

Mean weight diameter 8.85 mm 4.30 mm 4.56 mm 1.16 mm


6.4  Soil moisture

6.4.1 Water movement in the soil

Soil porosity depends on the space between soil particles or aggregates. It constitutes micro-pores and macro-pores (larger than 0.1 mm in diameter, eye brow thickness). Air and water move slowly in the micro-pores and freely or faster in the macro-pores. The flow of water in a soil is a complicated issue but approximately 10,000 times more water flows through a pore of 1.0-mm diameter compared to a pore of 0.1 mm. This means that macro-pores are crucial to the moisture supply of soils.

The size and number of macro-pores are a product of soil texture, aggregates, plant roots, organic matter, soil flora and fauna, cracks and fissures. A well-structured and biologically active soil maintains its aggregate structure and macro-pores under both dry and moist conditions. Tillage reduces the aggregate sizes but a virgin soil is more resistant to pulverisation than a soil under continuous ploughing.

Figure 6.4 is a schematic illustration of an infiltration moisture profile. The water in the soil is always in a dynamic state. It moves within the soil either in liquid or gaseous phases. The forces involved are gravity, capillary tension, vapour pressure and osmotic pressure. In effect, gravity and suction are the main forces crucial to the level of soil moisture.

When water starts to flow into a dry soil a wetting front is formed. This moves down into the soil. A dry and well-structured soil absorbs a lot of rainwater with the absorption rate dropping when the soil gets saturated. The suction gets weaker and gravity is what pulls the water down.

Behind the wetting front are the wetting zone, the transmission zone and the saturation zone. The saturation zone is formed when water starts to pond on the surface because the pore spaces below are full. The number of macro-pores determines how quickly the pore space fills with water. With more macro-pores more water moves into the soil before saturation (see Tables 6.2 and 6.3). Trapped air that cannot escape effectively prevents water from percolating into the soil. The more compacted the soil, the more air will be trapped restricting infiltration. This is a common problem under flatland cultivation regimes. If the ponded surface water is not held back it is lost as runoff.

Figure 6.5 shows the infiltration from a furrow into an initially dry soil after different periods of time (t1 < t2 < t3) (Hillel, 1982). At first, strong suction causes infiltration to be nearly uniform in all direction but when suction
decreases the gravitational gradient predominates. The infiltration rate is normally higher in a furrow between ridges than on flat land due to larger infiltration surface, better surface water holding capacity and less trapped air.

A soil that is low in organic matter has a weak and poor structure which easily gets pulverised when exposed to the physical forces of tillage. The grinding action of ploughing reduces the aggregate sizes drastically. When this type of soil gets wet and then dries, it often becomes permanently compacted. Few macro-pores are typical of these soils and rainwater infiltrates slowly through the micro-pores only. Another feature of this soil quality is rapid surface sealing and crusting when exposed to the impact of raindrops.

Around 90% of the rainwater enters freely into a living virgin soil through the macro-pores (Sandström, 1995). A highly drought sensitive and erosive cropping system is quickly formed when macro-pores are closed because the rainwater infiltration now depends on the micro-pores only.

Soil porosity is lost through compaction and pulverisation, both of which are enhanced by a decline in organic matter. It is important to ensure that the soil organic matter is maintained at an optimum level. Addition of organic matter may be achieved through various sources, including decayed roots, crop residue, farmyard manure, green manuring and composts. Table 6.2 demonstrates the relationship between downward flow of water in a wet soil and soil texture and aggregate structure quality.

A permeability level of 10 mm/h will cause runoff on flat land if rain intensity is above 10 mm/h. However, a thin compacted layer in the soil can reduce the downward flow drastically. Surface sealing and crusting, and ploughpans are typical features which restrict infiltration, increase greatly the risks of runoff, waterlogging and evaporation losses. Soil roughness, ridging and coverage of crop residue are essential factors in slowing down the speed of runoff and evaporation. In general, the differences in permeability in a specific soil are indications of a well or badly-managed soil.

If restrictions to water infiltration exist, plant root development is also restricted, since roots have problems penetrating a compacted, hard and dry soil. Compacted layers in a soil, such as ploughpans, are easily identified by studying deformation of weed roots or other plants at the end of the growing season. Where the taproot and/or seminal roots bend or split prematurely and look like cork screws, it signifies existence of a hardpan. In general, it is the size of the pores in the soil that determine the depth, thickness and the vigour of the root system.

A shallow and weak plant root system has a lower volume of soil and water to feed the plant. This restricts crop growth and decreases cropping security. It also has a smaller absorption area for the roots.
Table 6.2 Flow of water through a wet soil (permeability, mm/h)

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Organic matter</th>
<th>None</th>
<th>Weak</th>
<th>Intermediate</th>
<th>Good</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>Low</td>
<td>25–50</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adequate</td>
<td>50–250</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy loam</td>
<td>Low</td>
<td>15–25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adequate</td>
<td>25–120</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loam</td>
<td>Low</td>
<td>10–20</td>
<td></td>
<td>20–60</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adequate</td>
<td>60–120</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay loam</td>
<td>Low</td>
<td>2.5–5</td>
<td></td>
<td>5–20</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adequate</td>
<td>20–60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light clay</td>
<td>Low</td>
<td>&lt;2.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adequate</td>
<td>2.5–5</td>
<td>5–20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium/heavy clay</td>
<td>Low</td>
<td>&lt;2.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adequate</td>
<td>&lt;2.5</td>
<td>5–20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clay (sodic)</td>
<td>&lt;1</td>
<td>&lt;2.5</td>
<td></td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>


6.4.2 Field capacity and available water

For practical purposes, moisture in the soil can be divided into three classes:

- Gravity water
- Capillary water
- Hygroscopic water.

Gravity water is the water that moves downwards through the soil towards the water table by the force of gravity. This water remains for only a short time in the soil. Capillary water occurs as thin films on soil particles or as droplets or thin threads within the pore structure. It is the main source of water for plant growth. The amount of water retained by soil after gravity water has drained out is known as the field capacity. Hygroscopic water consists of a thin film held to the soil particles so firmly that it is not available to plant growth.

When plants grow in a soil with inadequate water, they start to wilt or droop. However, these plants recover if water is supplied reasonably quickly after this stage. However, if these wilting plants continue for long without water, they reach a point beyond which they do not recover even with additional water. This is known as the permanent wilting point. This term is also used to define the level of moisture content in the soil when this stage is reached. This stage includes all hygroscopic water and some capillary water. The amount of moisture in the soil above the permanent wilting point is known as the available water.

Figure 6.6 illustrates the relationship between field capacity and available water. Crucial steps in the managing of rainwater under drier conditions include:

- Maximising rainwater infiltration
- Creating favourable conditions to transfer gravity water to capillary water through improving soil structure and organic matter content
- Enhancing maximum root penetration and rooting depth to ensure maximum volume of water to supply and absorb water and nutrients
- Minimising water losses caused by evaporation, runoff and weed competition.
These interventions enhance field capacity and available water. In addition they minimise crop water stress, create good growing conditions and improve cropping security. Table 6.3 is a collection of soil moisture characteristics from various sources, which are essential when discussing appropriate cultivation practices in semi-arid areas. The first number in each column represents a weak soil aggregate structure with few macro-pores while the second shows the effects of good soil management. It is particularly the difference in soil organic matter, soil aggregate sizes and the number of macro-pores, which causes the differences.

Table 6.3 Typical soil moisture quantities (B of dry weight)

<table>
<thead>
<tr>
<th>Characteristics (% dry soil weight)</th>
<th>Soil types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry density (g/cm³)</td>
<td>Sand</td>
</tr>
<tr>
<td>1.76-1.60</td>
<td>1.68-1.28</td>
</tr>
<tr>
<td>Saturation (B)</td>
<td>15-30</td>
</tr>
<tr>
<td>Field capacity (B)</td>
<td>3-15</td>
</tr>
<tr>
<td>Permanent wilting point (B)</td>
<td>1-3</td>
</tr>
<tr>
<td>Available water (B)(mm/m soil)</td>
<td>2-10</td>
</tr>
<tr>
<td>Infiltration rate (mm/hr)</td>
<td>25-250</td>
</tr>
</tbody>
</table>

Sources: Roose (1996); Urio et al. (1983); Thomas et al. (1997); Pearson, et al. (1995).

Comments to Table 6.3:
- Higher soil density means a heavier and more compact soil.
- The lower the saturation rate, the quicker the soil gets saturated. Consequently, the soil does not absorb any more rainwater, leading to ponding and runoff.
- Field capacity refers to the water left in the soil when the surplus gravity water has drained down into the soil. It approximates the water left in the soil after 2 days of draining following a good, saturating rainfall.
- Permanent wilting point is the level of soil water content at which plant roots cannot absorb any more water from a dry soil, leading to plant death.
- Available water indicates the quantity of rainwater that can be stored in the upper soil (in mm per metre soil depth) to be absorbed by crop roots.
- Infiltration rate describes the speed at which water enters into the soil. Ripping and subsoiling break up the soil, substantially improving infiltration rate in most soils.
6.4.1 Crops and water

Evaporation is the process by which water, in form of vapour, enters the atmosphere from open water surfaces such as lakes, ponds or wetlands. Transpiration is the evaporation that takes place at the surface of plant leaves. Evapotranspiration is the total movement of water vapour into the air from land, which supports plant life. It includes transpiration from plants, evaporation from damp soil and any open water held in furrows or depressions following heavy rainfall or irrigation.

The level of transpiration is crop specific and dependant on the stage of plant growth. Water shortage restricts transpiration, affecting plant growth negatively. Therefore, unrestricted transpiration is a highly desired feature in crop production. Climate is one of the most important factors determining the crop water required by a crop for unrestricted optimum growth and yield. Crop water requirements are normally expressed by the rate of evapotranspiration ($ET$) in mm/day or mm/period.

The level of $ET$ is controlled by the evaporative demand of the atmosphere. This evaporative demand is expressed as the reference evapotranspiration ($ETO$), which predicts the effect of climate on the level of crop evapotranspiration. The value of $ETO$ can be obtained from most major weather stations. Table 6.4 shows approximate $ETO$ in mm/day for different agro-climatic regions.

### Table 6.4 Reference evapotranspiration ($Et_o$ in mm/day)

<table>
<thead>
<tr>
<th>Tropics</th>
<th>Mean daily temperature (°C)</th>
<th>Cool</th>
<th>Moderate</th>
<th>Warm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humid</td>
<td>&lt;10º—-----------------------</td>
<td>3-4</td>
<td>4-5</td>
<td>5-6</td>
</tr>
<tr>
<td>Sub-humid</td>
<td>—----------------------------</td>
<td>3-5</td>
<td>5-6</td>
<td>7-8</td>
</tr>
<tr>
<td>Semi-arid</td>
<td>20’—------------------------</td>
<td>4-5</td>
<td>6-7</td>
<td>8-9</td>
</tr>
<tr>
<td>Arid</td>
<td>&gt;30º—-----------------------</td>
<td>4-5</td>
<td>7-8</td>
<td>9-10</td>
</tr>
</tbody>
</table>

Source: FAI Irrigation and Drainage Paper ko. 33, 1986

It is possible to estimate an $ETO$ of 4–5 mm/day during the more humid cropping season in the LAMP/SCAPA programme area. The higher value is the estimate during hot and windy periods.

A crop coefficient ($kc$) is used to relate $ETO$ to the maximum crop evapotranspiration ($ET_c$ in mm/day) when water supply fully meets the water requirement of the crop. The relationship is shown below:

$$ET_c = kc \times ETO$$

The value of $kc$ varies with crop, development stage of the crop and, to some extent, the wind speed and humidity. For most crops the $kc$ value increases from a low value at the time of crop emergence to a maximum value during the period when the crops reaches full development, and declines as the crop matures. Figure 6.7 illustrates a typical crop coefficient ($kc$) curve.

The $ET_c$ should match with effective rainfall ($R_e$), which is highly dependent on tillage and soil and water conservation techniques. If there are runoff and evaporation losses, the efficiency of rainfall is substantially reduced. The ideal situation is when $R_e > ET_c$, because the crop can then grow to its maximum without water stress.
Daily assessment of the balance between $R_e$ and $ET_c$ is necessary for good irrigation management. However, monthly figures may be used in studying the appropriateness of the existing and alternative farming systems when relying on rainfall alone. This is particularly important when determining the choice of crops and cultivation technique in semi-arid areas, since the negative effects of water stress are different during the crop cycle.

As an illustration, the decrease in yield due to water deficit during the growth period is relatively small for the vegetative and ripening period, but comparatively large for the flowering and yield formation period. This speaks in favour of building up soil moisture reserves to overcome drought periods during critical growth stages. Another important aspect is the low utilisation of fertilisers in a crop suffering from water stress. Crops differ in their tolerance of a water deficit. Sorghum, for example, can tolerate drought better than maize.

6.4.4 Rainwater harvesting

Rainwater harvesting is a central part of the management of conservation tillage in semi-arid areas. The main objective should be to prevent runoff, and catch the raindrops where they hit the ground. Rain should infiltrate as soon as possible and be stored in the soil to be absorbed by roots and to recharge the groundwater. The term rainwater harvesting is also used for catching runoff water in tanks or dams. However, to avoid confusion the latter technique is referred to as runoff water harvesting.

6.5 The effects of ploughing

6.5.1 The situation in Babati area

Tillage studies in Babati area have shown that ploughing was the main cause of serious land management problems. Contrary to popular belief ploughing is not the best tillage option. It has proved inappropriate for
the semi-arid areas around Babati, Kiteto and Simanjiro Districts. This is also true for Singida Rural, Arumeru and Arusha Urban Districts. This section analyses why the plough ought to be replaced with better conservation tillage techniques.

There is need to improve on the existing technique of ploughing using oxen and tractors. Ox ploughs commonly used in Tanzania are shown in Figure 6.8.

Ploughing using oxen is shown in Figure 6.9 which also illustrates the ploughpan and typical root formations (of a pigeon pea plant) in fields exposed to long periods of continuous ploughing. Pigeon pea has strong taproots that penetrate deep into the soil. The roots shown in Figure 6.9 are clear evidences that a ploughpan restricts root depth. This type of root deformation is prevalent throughout the vast programme area.

6.5.2 The ploughpan

During ploughing soil is cut, moved, inverted and pulverised. Approximately 2,500 tonnes (t) of soil per hectare (250 truck loads of 10 t each) is moved by ox ploughing. The cutting action of the plough effectively closes the pores under the share (Figure 6.10). The fine particles derived from the pulverisation process move downwards and complete the closing and sealing of the pores. The trampling of the ox in the furrow bottom also contributes to this process. After a while, a ploughpan is formed which prevents entry of water and roots beyond the 10–15 cm plough depth of the soil. This sealing process is more pronounced in moist soils. The hardpan thickens and hardens with each ploughing operation. In subsequent ploughing operations the hardpan (also known as the ploughpan) becomes so thick and hard that the plough simply slides on top of the impervious layer. The result of this scenario is that subsequent tillage becomes shallow and the soil above the pan becomes pulverised and sensitive to crusting.

The ploughpan formed by an ox-plough is 5 to 10 cm thick, while that of a disc plough is 10 to 20 cm thick. The pan has very few macro-pores and roots hardly penetrate the compacted layer except where there are occasional cracks. After several cropping seasons this results in a shallow, highly drought sensitive and low yielding cropping system. Moreover, the shallowness makes the crops very sensitive to weed competition.
Aggressive grass weeds have a devastating effect on shallow crops with poorly developed root systems (whose ability to absorb nutrients is weak). Another problem of the plough pan is the dislodging of tall crops due to poor anchoring by the shallow root systems.

The standard recommendation to avoid formation of ploughpans is ploughing at different depths. Unfortunately, this has not worked in Africa and most of the tropics as farmers usually discard the depth adjustment claiming that it is not useful resulting in no possibility to set the plough properly. The extension work on setting the plough started before independence in Tanzania with hardly any effect to date. It is therefore realistic to anticipate that it may not work in the future either, and the recommendation to vary the ploughing depth will not be followed by the farmers. Though an important measure of preventing ploughpan formation, this practice has not been adopted by farmers and remains a research and extension services exercise.

Deep ploughing under more dry conditions is also recommended in heavier soils with good organic matter content for rainwater harvesting. The large clods formed ensure efficient rainwater infiltration. A serious constraint to this practice is heavy draught power requirement and the need for both draught animals and implements to be in excellent condition. These conditions are seldom met, rendering this technique a mere recommendation with most farmers maintaining shallow ploughing.

A soil with a ploughpan saturates much faster with water as the infiltration process is drastically inhibited. As a result, even a short rain can causes runoff hence very poor rainwater utilisation efficiency. Another serious problem discussed earlier is the of crop nutrients dissolved in the runoff water. These can be substantial. The combination of ploughpan and inverting the soil reduces the number of useful soil organisms such as worms and digging insects.

The negative effects of ploughing are seen in most soils ranging from heavy to light. The worst ploughpans are usually formed in loamy soils. For example, sand on top of a concrete hard ploughpan is very common in the LAMP District of Kiteto. Observations during the 1997/98 season clearly showed that a pan was formed in Landanai by the cutting action of hand hoeing. Root deformation in acid soils is similar to that observed in a ploughpan. Usually, the negative effects of acidity are worse with decrease in organic matter.

**6.5.3 Soil organic matter**

Development of the ploughing technique for effective inversion of the top layer of soil was made in the cooler northern hemisphere. The soils in these regions have a lower rate of chemical reaction. Effective inversion of soil may not be the desired feature in warmer tropical soils which have a higher rate of chemical reaction. Rate of decomposition of crop residue, for example, is four times faster in Nigeria than in cooler England (Godwin, 1990).
During the inversion phase of ploughing the organic matter on the surface is thoroughly mixed into the soil and the break down process (oxidation) is speeded up drastically. Trials from Zimbabwe (Elwell, 1998) show that it is possible, under semi-arid conditions, to reduce the organic matter content in some soils by 50% in a year or two through ploughing. A good soil may deteriorate in a relatively short period of time.

Soil organic matter contains essential crop nutrients and is a key component in enhancing availability of other nutrients to the plants. A soil exposed to rapid depletion of organic matter quickly loses fertility and a large proportion of the released nutrients are lost to the crops through leaching and/or runoff water.

The structure and strength of soil aggregates are highly dependent on the organic matter content. Decrease in organic matter results in weak soils that are more susceptible to compaction and crusting. The water holding capacity of a soil is also closely related to the organic matter content, and soil compaction. When the organic matter content declines and the soil compaction increases, the water holding capacity also declines.

A newly ploughed virgin soil produces very good crops initially due to the abundance of soil nutrients released which are quickly lost if not replaced. This early response has contributed to the conviction by agriculturists and farmers that ploughing is a suitable tillage operation. The positive result is also enhanced by the weeding effect of ploughing. Several years later when the crop yield declines it is apparently difficult to link it to ploughing.

6.5.4 Surface sealing

Up to 90% of the soil particles carried away by erosion are dislodged by raindrops falling on exposed soil (splashing) and only about 10% by the running water itself. On a pulverised bare soil that is low in organic matter and low in resistance to raindrop impact and splashing, a surface seal is quickly formed during a rainstorm. This seal causes heavy runoff and erosion. On drying, the formed crust impedes aeration, restricts crop growth and ensures continued poor infiltration. The ploughing operation contributes heavily in creating these conditions with subsequent losses of water, topsoil and crop growth potential.

Measures that improve plant and soil coverage are very important soil maintenance factors. They prevent surface sealing and runoff, and enhance rainwater harvesting. The standard recommended row spacing for an animal drawn tillage system for major crops such as maize, sorghum and sunflower is 75 cm. This is a favourable spacing for most crops for a conservation tillage system because approximately 25% less bare soil is exposed than with 90 cm row spacing.

A problem that is overlooked on a flat and weak soil surface is that soil air cannot escape fast enough when rainwater enters the soil. This results in trapped air, which adds another strong barrier to rainwater infiltration, in addition to seals and crusts. This problem is solved with ridging, as the corrugated land reduces the risks for surface crust formation and allows air to escape easily.

6.5.5 The desirability for ploughing

The main reason reported for ploughing 2 or 3 times before planting is the control of grass weed. Both researchers and farmers recognise weeding as a major bottleneck in crop cultivation. Farmers consistently claim that ploughing before planting is crucial for weed control making this an operation difficult to give up. However, new findings indicate that new weed seeds germinate because of being ploughed up to the surface. Hence while ploughing the land to fight weeds it is possible to promote weed growth.

Despite these disadvantages ploughing remains the single most popular tillage technique in African smallholder farming. Are farmers right or have research and extension missed better alternatives for controlling weeds than ploughing and hand weeding? Is damaging a soil a necessity to control weeds?
Most animal draught power manuals refer to the need for harrowing after ploughing to ensure optimum seedbed formation. This operation pulverises the soils further and accelerates all negative aspects of ploughing. For example, the common spike-tooth harrow does not work in fields covered with crop residue. A fine and trash free tilth is also a precondition for using the standard inter-row cultivator for weeding. The choice of mechanised weeding determines the choice of primary tillage.

When a soil gets compacted by ploughing more ploughing operations are required to open it for cropping. It is, therefore, easy to enter into a vicious circle in which more power is required to break an even harder soil. A lot of clay soils are abandoned in the programme area due to this reason.

A number of well known soil management/tillage experts (such as H. Elwell; B. Oldreive; D. Gibbon; H. Dibbits and others) believe that the plough is the single most destructive tillage implement in the semi-arid tropics and that its continued use will ensure low crop production and food insecurity. Indeed, some authors recommend banning the plough to avoid natural disasters in Africa.

The ox-plough is the most widely used implement for mechanised tillage in eastern and Southern Africa. There is a need to make the best use of this implement by minimising its well know negative effects on soil and rainwater management. Conservation tillage, though desired, may take time before it achieves the same level of popularity as ploughing.

The LAMP experience shows that a combination of ox-ploughing and ox-drawn conservation tillage, such as ripping and sub-soiling, substantially improves crop yield. Positive effects of one sub-soiling last an equivalent of 3 years of continuous ploughing. Heavy weed infestation may make the introduction of conservation tillage a non-starter and its initial combination with ploughing is an option to reduce the weed population. The plough remains for use in deep ploughing on heavy soils for rainwater harvesting. It also used for forming ridges and to mechanically construct large numbers of soil conservation structures.

Good ploughing has better returns than bad ploughing, although the latter dominates. If the main reason for ploughing is to control weeds, then a farmer should always aim at the most effective way of achieving good weeding even with the plough. While using the plough, ensure good workmanship which minimises the well-known negative effects of shallow ploughing.

To reverse the present negative crop production trends, alternatives to the old plough have to be sought. Weeding is one area which requires urgent attention.

**6.6 Methods to restore land damaged by ploughing**

**6.6.1 Fallow**

The oldest and most common method of regaining soil fertility of an exhausted, compacted and weed infested soil after a cropping period is to leave the land fallow. Fallowing is a cheap but slow process that works only in sparsely populated areas. Today, this practice is not sustainable because the bush fallow period is too short (due to land pressure) for satisfactory restoration. The length of fallow has to be more than 15 years to have a real effect on soil fertility, and more than 5 years for improvements in soil structure. An active fallow planted with selected deep-rooted legumes, like velvet beans, reduces the recovery time substantially. However, if the plough is used extensively after fallow period, the land quickly reverts to pre-fallow condition.

**6.6.2 Improved tillage practices**

A starting point when restoring land damaged by ploughing and erosion is to break the ploughpan and reform macro-pores. This can be achieved by mechanical and/or biological means. The most effective way is cracking up the pans using a chisel point (Figure 6.11). The lifting and side forces of the chisel tine effectively
break the ploughpan and form a large number of new aggregates/clods and macro-pores which ensure good water infiltration and deep plant root systems. This operation quickly brings new life into a poor and compacted soil.

The ripping and sub-soiling operations are more effective on dry soils. The positive effects of ripping/sub-soiling last for at least three seasons, depending on soil and type of tillage. Conditions that encourage formation of the ploughpan must be avoided. Ploughpans formed by ox-ploughs can usually be broken up by ox-drawn rippers/sub-soilers, while those formed by tractor drawn disc ploughs are thicker and harder and will usually require tractor drawn sub-soilers.

Ridging is an effective traditional method which improves rainwater infiltration, aeration, soil fertility and weeding, and controls erosion. It is a method which deserves more attention and adoption. Runoff from a bare flat surface is much higher than that of a ridged surface along the contours. Therefore, a properly designed cropping system on ridges is usually superior to flat land cultivation. With proper ridging practices done along the contours, the need for soil conservation measures is reduced thus making it possible to control runoff and erosion on land with slopes up to 12–15%. However, ridging with a common ox-drawn ridger on a ploughpan is a bad practice, as the ridger just slides on top of the pan. The flat and wide ridger share (Figure 6.12) has a similar cutting action as ploughing and does not go below a ploughpan. The cropping system that follows will be shallow and exposed to high evaporation losses and serious erosion risks. The combination of ploughing and ridging is not sufficient to properly control erosion.

**Figure 6.11** Breaking of ploughpan.

**Figure 6.12** The standard ridger body assembly.
Sometimes the plough is used to make ridges by running back and forth in the same furrow and moving the soil either way like a ridger. This is a simple method but takes double the time a ridger does. The real drawback occurs when closing of the furrow bottom with the ploughshare. The two passes effectively close the macro-pores for a width of at least 25 cm, restricting water infiltration substantially. Disc ridgers work in a similar way to the disc plough, forming thick ploughpans, thus making their performance questionable.

The situation is very different with the ox-drawn ripper/ridger which has extended wings that form ridges. The basic ripper unit is shown in Figure 6.13, fitted to the standard plough beam. A more detailed illustration of the implement is shown in Figure 7.1 in the next chapter. The ripper tine goes below the ploughpan, breaking it up to form a large number of new macro-pores in the furrow bottom. In this way, all the benefits from good ridging are reaped through a better-designed implement. Water infiltration is particularly improved compared to when a standard ridger or a plough are used to make ridges.

The ox-drawn ripper/ridger is also an excellent tool for mechanised weeding, as will be described in detail in Chapter 7.

The ripper/ridger can be used to construct contour bunds during the dry season. A ripper can make kilometres of bunds in a day during the dry season and ought to be a key implement when making soil conservation structures. Only the final touches require some hand digging. Contour bunds damaged by cattle during post harvest grazing are easily rebuilt with a ripper/ridger before the rains.

6.7 Biological practices

Experience shows that it is necessary to break a ploughpan before changing to a no-till or reduced tillage system. Inter-cropping with deep-rooted crops, such as pigeon peas and lablab (*Lablab purpureus*, earlier called *Dolichos lablab*) beans also weakens the ploughpan or reduces the risk of new ones being formed. Frequent application of farmyard manure and or compost to the soil is a method for gradual self-healing, which improves soil structure and weakens a ploughpan.

6.7.1 Infiltration and runoff

A small shower of 10 mm can cause significant runoff on a ploughed, poorly structured and pulverised soil. If this ploughed land is properly ridged along the contour with a standard ridger on top of a ploughpan, the
soil can absorb up to 15–25 mm of rain before runoff takes place in the furrow and/or overflows the ridge (Figure 6.14). Very little water passes through the ploughpan and most rainwater remains above. Part of the water infiltrates the ridge and the rest is left as a pool in the furrow or runs off.

Figure 6.14 Infiltration moisture profile after ridging on top of a ploughpan.

The situation is greatly improved with tied ridging (Figure 6.15). Properly made ties can hold as much as 50 mm of rain on top of a pan before breaking. The ability to infiltrate the rainwater determines the total amount of rain absorbed before runoff breakthrough takes place. In the case of ridges on top of a ploughpan, the height and thickness of the ties determine the quantity of rain held before breaking through the ties.

Figure 6.15 Tied ridges.

Ties are constructed by hand or by a simple tie-maker made from a half disc of a disc plough pulled by a donkey/oxen (Figure 6.16). The half disc scrapes the soil as the animal moves forward. When enough soil is heaped in the furrow the operator lifts the disc and a tie is formed. He then puts the disc down and continues along the row forming new ties after each 3–4 m. This is a simple and fast operation.

Figure 6.16 Tie-making of ridges with a donkey in Zimbabwe.

When the ridge is formed using the ripper/ridger (along the contour), the pan is broken up by the chisel point enabling water to infiltrate the soil at a good rate through the newly formed macro-pores (Figure 6.17). The soil can then absorb a heavy downpour without runoff. Some stubble mulch in the furrow bottom assists in maintaining the high infiltration rate. The type of soil and structure determine infiltration rate but, in general, up to 50 mm/day is absorbed without runoff when a ripper/ridger system along the contour is instituted.
Further improvement is achieved with tied ridging. Through better tillage practices, the land can absorb up to 150 mm of rain in a day before breaking through of the ties. Rainfall of above 100 mm/day is extremely rare in the programme area, therefore a technique which can absorb up to 150 mm rain per day must be considered very safe and highly appropriate for a semi-arid areas. As demonstrated in Figure 6.17, the centre of the ridge is drier than the furrow bottom. This problem is more pronounced in wider ridges than in narrow ones. Therefore, ridges spaced at 75 cm suffer less from water stress than ridges 90 cm apart.

Establishing a crop on top of a ridge is difficult under dry conditions as the rainwater drains off to the furrow bottom. However, this problem is easily overcome by splitting the top of the ridge and forming a planting furrow with a ripper ridger as shown in Figure 6.18. In this way, about one-quarter of the rainfall received is directed to the emerging plants ensuring that they have a good moisture supply.

When the crop roots develop they quickly reach the lower water reserves where they are well supplied with moisture. The planting furrow can be closed once the plant has reached a height of 10–20 cm. This opening and closing of a planting furrow may be considered as the first and second weeding, respectively. Fertilisers and farmyard manure should be placed in this planting furrow for optimum utilisation of crop nutrients for the desired plants.

Waterlogging and poor aeration are serious problems in many heavy soils such as black cotton soil (*Vertisols*), but the negative effects are greatly reduced with ridging using a ripper/ridger. The evaporation losses are high on ridges sitting on top of a ploughpan, but low on ridges formed by a ripper/ridger because the water is stored in the soil and therefore not exposed to evaporation.
Another important advantage with properly formed ridges along the contour is that the slope has little effect on runoff. Runoff is slowed down by the ridges. The risks of a breakthrough by water held in the furrow by the ties is less with a 75 cm row spacing than with 90 cm, since there is 20% less water between the ridges and 20% more ridges and ripped furrow bottoms to ensure maximum infiltration.

**Traditional ridging in Mama Isara**
Deep ridging by hand along the contour has been practised for some 300 years on the steep slopes in Mama Isara, Mbulu District, which neighbours the programme area. Maize is planted in moist soils at the end of the long rains, and harvested at the end of the dry season. The ridges harvest rain and enough water stored in the soil to develop a good maize crop 4–5 months later. Irish potato is the main crop during the rains. Crop residue and farmyard manure are placed on top of the ridges in this cropping system. There are no terraces, only ridges and mulch to control runoff on slopes up to 60%. This cropping system has worked for a long time in this heavily populated hilly area. This method is, therefore, highly sustainable and effective in maintaining soil fertility. The ripper/ridger forms a ridge similar to that of Mama Isara.

6.7.2 The agricultural potential

Rainwater losses, such as runoff and deep drainage, are associated with crop nutrient losses. These nutrient losses can be substantial. A weak root system has a low efficiency in absorbing plant nutrients from the soil. Only actively growing roots can absorb water and nutrients. Frequent crop water stress reduces this ability further. Consequently, crops growing in ploughed and compacted fields have low rainwater and soil nutrients utilisation rates. Indeed, this highly wasteful practice (ploughing) has led to the decline in agricultural potential. With a conservation tillage practice that breaks up the compacted soil allowing for active root growth, agricultural potential can be increased to a much higher level without extra farm inputs.

6.7.3 Important considerations for discussion

The common ploughing technique, which inverts the soil, is as far as one can get from any system that maintains the soil in its original virgin condition. Ironically, the recommendations for good ploughing quickly damage a good tropical soil.

An important issue that is seldom discussed is how feasible it is to realise good soil conservation in semi-arid areas with the plough. Should one concentrate on the symptoms (runoff) or the causes (soil damaged by ploughing)? Should one avoid runoff, control it or both? It is apparent that part of the extension service recommends techniques which encourage land degradation, while another part endeavours to repair the damage. Why not avoid the damage in the first place and repair only when needed!

The present trend of separating tillage and soil conservation results in an enormous workload over a long period to safeguard sustainability in farming systems. A simple conservation tillage system solves the problem quite easily.
### 7 Animal draught power and conservation tillage

#### 7.1 The basic tillage implements

#### 7.1.1 Background

The objective of the first section of this chapter is to introduce the ox-drawn implements used for conservation tillage in the LAMP/SCAPA area. The first implement is the common ox-plough illustrated in Figure 6.8. This implement cannot meet the demands for a sustainable and productive cropping system in semi-arid areas. A more practical alternative for achieving sustainability is through conservation tillage.

There are hundreds of thousands of ox-ploughs throughout Tanzania, and it is practical to use these existing implements and modify them to fit the requirements of conservation tillage. This is done by unbolting the plough body and replacing it with other attachments, such as a ripper unit, using the same holes on the plough beam (Figure 7.1). All other pieces should remain on the plough. If the farmer wants to plough he/she simply refits the plough unit back to the plough beam.

The conservation tillage implements shown below were originally designed and manufactured in Zambia. The ripper/ridger is a joint Tanzanian/Zambian effort meant to extend the range of desired operations.

Ripping with oxen is an old technique still being used by a large number of farmers in Northern Africa, Ethiopia, Latin America and Asia. The advantage of this technique is realised all over the world. The Magoye Research Station in Zambia has designed a strong ripper suitable for the tough Southern African semi-arid conditions. To reduce the costs, the ripper is fitted to the standard plough beam. Instead of buying a complete implement, a farmer who has a plough can simply buy the ripper unit and fit it to the old beam. In this way it is possible to reduce the implement costs substantially. The same applies for both the sub-soiler and the planter. This system will give the farmers a wide choice of tillage options centred on one basic plough beam. These implements are marketed by the Tanganyika Farmers’ Association, in Tanzania. Local manufacturing has started in Moshi (Nandra Engineering), making the technique available in Tanzania.

![Figure 7.1 The Magoye ripper assembly.](image-url)
A successful introduction of the animal drawn conservation tillage technique depends on the skill and efficiency of the extension service and how well they can publicise the technology and to create demand for it. Properly trained farmers and draught animals are crucial to the field application. The private sector also needs to meet the challenge of manufacturing, marketing and servicing of required conservation tillage inputs.

7.1.2 The Magoye ripper

The Magoye ripper unit is shown in Figure 7.1, attached to the old plough beam. Apart from the old beam, the other components that may be left intact for use by the ripper are the handles, plough wheels and the depth adjustment facility. The ripper body is bolted to the beam in the same holes as the plough body. The short wings are also attached with the same bolts. These are used for ripping and planting. The hard steel chisel point is then fixed with standard counter-sank plough bolts.

The Magoye ripper functions by breaking open a narrow furrow while creating macro-pores and developing a good seedbed for planting a crop. During planting, a person follows behind the ripper, drops the seeds in the furrow and covers them. The ripper may be fitted with extended wings to enable it be used for weeding. It can also be equipped with chisel points of different width for deep penetration or weeding.

The ripper is designed for a plough beam thickness of 37 mm, which is the standard size in Southern Africa. However, as the common plough beam in Tanzania is only 28 mm thick, there is a need to insert two spacers or u-clamps (Figure 7.1 (c)) to fill up the space between the beam and the sub-frame to get a proper fitting. Originally, the idea was to keep the depth adjustment for the plough also for the ripper. But this did not work well and most farmers discarded it. The ripper goes deeper than the plough and therefore it is essential to set it properly. The new depth adjustment (Figure 7.1 (d)) is strong, cheap and easy to use.

The normal chain used for ploughing is too short for ripping. It must be extended by 1 m. Without this extra chain length, the ripper will not go down to the required depth of 25–30 cm, which is usually required to break a pan formed by an ox-plough. The alternative is to use one and a half chains. Furthermore, the draught power requirement is often higher with a shorter chain due to unfavourable geometry of the power train.

Figure 7.1 (e) shows a ripper/ridger unit. The extended wings are fitted with adjustable extended wings. In this way the ripper can be used both for ridging and weeding at wider row spacing. A rudder for steering the ridger can be fitted for split ridging, and precision planting and weeding. It prevents the implement from moving sideways. However, experience has shown that a farmer can manage well without the rudder. The ripper/ridger can replace the common ridger in the market for most operations. It is cheaper and more versatile. Its other benefits are:

- It is not dependant on the plough for ridging
- It does not create hardpans and breaks up ploughpans
- It creates optimum conditions for rainwater infiltration and retention, and reduces evaporation losses
- It is an excellent weeding tool
- It is effective in conserving the soil and in constructing soil conservation structures
- It speeds up work and saves labour.

The ripper/ridger unit improves the basic Magoye ripper and turns it into an excellent universal implement for conservation tillage.

7.1.3 The sub-soiler

The sub-soiler is a piece of equipment, similar in design to the Magoye ripper, which can penetrate down to a depth of 30 cm (Figure 7.2). The intention is to reach the sub-soil and break any hardpans present. Usually one needs two pairs of strong oxen for this sub-soiling operation during dry conditions. This type of sub-soiler can break a heavy pan formed by extensive ox ploughing. The chisel point (also known as the jumper
bar) is made of a hard drill steel such as those obtained from mining drill rigs. The sub-soiling operation is usually carried out with row spacing of 75 cm, which is enough to open up most soils.

The draught power requirement is heavy for deep tillage in hard soils. An excellent method to achieve desired depth for ripping and sub-soiling is to till in stages. The first operation is to mark up the field by ripping/sub-soiling down to 10–15 cm with the long weeding yolk (150 cm between the necks of the oxen giving a row spacing of 75 cm) to achieve parallel rows. The ripper/sub-soiler should then be set for deeper work in the previously worked furrows. The plough yoke can be used with the oxen having the furrow to be deepened between them. In 2–3 operations it is possible to sub-soil to sufficient depth in dry hard soils with a pair of oxen. A shorter yoke is easier to manage under heavy pulling conditions. With this system, even small oxen and donkeys can do sub-soiling down to the desired depth.

The plough beam of the sub-soiler needs to be equipped with an extended beam to enable deep penetration and easy pull. This implement also needs the extended treck chain of 1 m, as with the ripper. The chisel point (jumper bar) can be moved forward as it wears out. In this way the chisel point will last for a long time before being replaced. The bolt marked (3) in Figure 7.2 is used to fix (hold) the chisel point in place, while bolt (4) adjusts the forward movement.

### 7.1.4 The ripper planter

The Magoye ripper can be equipped with a planter unit, which is hitched to the beam behind the ripper through a flexible joint (Figure 7.3). It is then possible to do direct drilling in uncultivated fields, covered with crop residue, even before the rains.

The planter has been developed to establish a crop early and well in a shorter period with less labour and farm power. It is a simple and sturdy device with few moving parts fitting well into the dryland farming/conservation tillage concept. Work is in progress to modify the planter to be able to sow on ridges. In principle, the planter consists of a seeding unit (seed hopper, seed tube and wheels), link system with a bracket fitted to the plough beam and the seed covering plates (Figure 7.4). Attached to the Magoye ripper, the planter drops the seed in the furrow opened by the ripper unit, and then closes it. If the oxen know how to pull a ripper properly, they can also perform planting in parallel rows. Figure 7.5 shows the detailed parts of the planter.
The link mechanism between the planter and the plough beam will ensure that the planter follows behind the ripper in a flexible way with both wheels having ground contact. When the ripper is lifted at the end of a row, the planter disengages the wheels from the ground and stops working. The planter will start working when the ripper tine enters the soil in the next furrow.

The metering mechanism is a simple cell wheel driven directly by the planter wheels. There are different cell wheels according to seed sizes and plant spacing. For example, a seed wheel with 4 holes will drop the seeds every 25 cm. The number of seeds dropped from each hole in the cell wheel depends on the size of the holes. Presently, there are 3 cell wheels accompanying the planter, one for larger seeds, like maize and beans, and one for smaller seeds (like sorghum). An extra cell is usually supplied. This one is without holes, and can be drilled according to specific seeding requirements. The number of holes in the cell wheel can easily be reduced by filling them with some wet clay. The same technique can also be used for making the holes shallow, thereby reducing the number of seeds per hole. Another adjustment is the rubber scraper which is resting on the seed wheel to prevent extra seeds from falling into the seed tube (Figure 7.5, 9–10). If the rubber is tightened, all seeds reaching above the hole will be scraped off. With a looser fitting, more seeds are released from each hole.

The cell wheel is changed by turning each wheel in the opposite direction. This motion will unscrew the shaft halves which hold the cell wheel. A new cell wheel can then be fitted by turning each wheel in a reverse direction to that of opening. When sowing the operator can actually see the seeds falling into the soil. This assures the farmer that the machine works and that the seeds are properly placed into the soil. The planter is also fitted with two seed cover plates that closes the planting furrow. The thickness of the covering layer of soil is adjusted by the length of the chains.

**Planter calibration**

Before the planting can take place, it is essential to know the desired plant spacing and the number of plants per plant hill; the farmer must consult the village extension staff on this issue. Furthermore, it is essential to know the viability and germination rate of the seeds. It is always better to have some more plants growing than needed then thin the stand, than to replant later.

The next step is calibrating the planter to get the desired plant population. This is achieved in two ways:

- Operate the ripper/planter for 10 m with very shallow setting so that all seeds are visible on the ground then count the seeds.
- Rig up the planter in upright position with the wheels slightly above the ground. Turn the wheels 10 times (this is equal to 10 . Collect the seeds under the seed tube and count them. For example, if 33 seeds had dropped during a 10 m or 1,000 cm run the row spacing would be: 1,000 cm/33 = 30.3 cm or 30 cm in reality.

If it is desired to have 2 plants, each 50 cm apart, then a cell wheel with 2 holes is needed, with each hole holding 2 seeds. Sometimes, with poor seed germination, it might be necessary to plant 3 seeds per hill instead of 2. This means that a suitable cell wheel must be selected or new holes can be drilled as per required specifications.
The calibration process should be repeated until the right seed rate and planting distance is obtained. It is necessary for the extension staff and the distributors to train the farmers on how to perform this task, particularly if expensive seed is used.

There are not many moving parts on the planter. However, it is essential to ensure that bolts are properly tight and that pins have washers and locks. The planter works under very dusty conditions, hence it is important to oil the different parts. Dust sticks to oily parts, giving rise to a grinding paste, which is problematic. A few drops of oil on the threads is alright, but they must not be allowed in the bushing where the axle halves are fitted to the seed tube.

**7.1.5 Timing of tillage work**

The results of deep ripping and sub-soiling depend on the available animal draught power. Better operations result if the soil is dry. One can choose the following options to do ripping and sub-soiling:

- Rip or sub-soil before the rains. The soil hardness is high and hence the operation will most likely
require two pairs of oxen in good condition.
• Ripping in stages is an excellent practice to reach required depth when draught power is limited.
• Rip or sub-soil during early rains, after some showers. The ground is softer and one pair of oxen may be able to do the operation.
• Rip or sub-soil after harvest when some moisture is left and the ground is still relatively soft. The oxen are often in their best condition at the end of the rainy season. Usually, this is the best time for heavy work. The only disadvantage with working at this time is the presence of crop residue in the field. These residue pose an obstacle to the tillage operations. Fortunately, it is possible to arrange the residue by hand with a stick to make lines free for tillage implements. Another option is to align the crop residue between the crop rows when harvesting. It then becomes easy to do deep tillage in heavy trash. Post-harvest management of crop residue is an important aspect with these options.

### 7.1.6 Prices of implements

Table 7.1 shows the prices of various conservation tillage implements, for the period indicated, as sold by the Tanganyika Farmers Association.

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Magoye ripper/ridger unit with depth adjustment and 1 m treck chain</td>
<td>36,700</td>
<td>43,200</td>
</tr>
<tr>
<td>Sub-soiler with extended beam</td>
<td>23,400</td>
<td>27,000</td>
</tr>
<tr>
<td>Ripper-planter unit</td>
<td>34,000</td>
<td>54,000</td>
</tr>
<tr>
<td>Complete ox plough (old stock)</td>
<td>55,000</td>
<td>55,000</td>
</tr>
</tbody>
</table>

*Tanganyika Farmers Association quote, May 1999

The above prices originate from the 1997/98 season. Transport from Zambia is excluded and a small subsidy added. The estimated prices today for locally manufactured implements (in Tanzania) are expected to be a bit higher, though still internationally competitive.

### 7.2 Conservation tillage treatments

#### 7.2.1 Using the ripper/ridger combination

The starting point for the ADP/conservation tillage technique is the introduction of a combination of ripper and ridger into a traditional ploughing system. Such a system is often based on oxen (or tractors) powered ploughing and planting, followed by hand weeding. Farmers who base their mode of production on a minimum risk strategy will not accept drastic changes. They take cautious steps and want to move slowly. The following crop establishing systems are practised in various areas:

- Dry planting on unploughed land (e.g. Kiteto)
- Planting at the onset of the rains after ploughing (e.g. Simanjiro)
- Planting during the rains after 1–2 ploughings (e.g. Babati).

The key issue considered when establishing a crop is a good seedbed for sowing. Any tillage operation practised between the crop rows has no effect on germination and crop establishment. This means that strip tillage is all that is necessary for producing a crop. However, the next important consideration is the question of weeds, which start to grow as soon as the rains come. One can start the weeding process, by mechanical means, between the plant rows as soon as crops emerge. An alternative weeding procedure involves the use of herbicides.

Moving from the traditional ploughing system to the use of the ripper/ridger would involve the following steps:

1. Breaking the ploughpan: This can be done by the ox-drawn sub-soiler or the ripper, preferably before the onset of the rain. Sub-soiling at a row space of 75 cm is ideal for this operation. Most likely the
rows will not be parallel at this stage as the soil is very hard and the oxen will tend to meander. This is not a problem for the next operation.

2. Ripping and planting: When dry planting is the desired option, the ripper should be used for planting just before the onset of the rain. The seeds are dropped in the ripper furrow and covered. If the ploughpan is not well formed and hard, operations 1 and 2 may be combined.

3. When planting at the beginning of the rain, the weeds tend to grow faster than the crops. Most farmers want to plough to control the weed. If there were serious weed infestation it would be futile to stop the farmer from ploughing initially. Planting should then be done with the ripper. A single ploughing operation will not jeopardise the benefits of sub-soiling in the short run.

4. The rainwater harvested by sub-soiling or ripping is useful to the crop, although weeds also benefit from it. Indeed, a heavy weed growth can utilise and consume the infiltrated and stored rainwater before planting if weed control is neglected.

5. Usually, there tends to be heavy weed infestation in fields planted during the rains. The common practice is to plough 2–3 times before planting to suppress or kill the weeds. However, the practice of tilling the land makes the soil bare and exposes it to destructive forces of rain. Such practices should be discouraged. Instead, a useful cover crop should be planted to protect the land while waiting for the rains. Alternatively, a herbicide can be sprayed on the weeds and the killed vegetation used to protect the soil. At sowing time the ripper can be used to plant through the dead weed turf.

6. Weeding can be done with the ripper or ridger as soon as the planted crop germinates. At least two weeding operations are required. Research findings on conservation tillage show the benefits of late weeding. This prevents late weeds from setting seed and thus reduces weed intensity in subsequent cropping seasons.

7. Some farmers use the plough yoke for close ripping, instead of ploughing. This gives a good weeding effect on grass weeds. For example, it pulls up the roots of the couch weeds, which then dry up.

Field experience shows that farmers readily accept a gradual change from ploughing to using a ripper/ridger combination for conservation tillage.

### 7.2.2  Ripping in crop residue

The ripper/ridger combination can work well in quite heavy crop residue. It is, however, advantageous to chop long stalks down to 30-cm lengths to avoid clogging and improve performance. Such chopped crop residues often fall into the furrow bottoms, thereby improving the infiltration characteristics of the soil. Burning the stalks for easy tillage should be discouraged. Parly covered stubble (stubble mulch) protects the soil and improves rainwater infiltration. Alternatively, the crop residues may be used to form line barriers to overland flow.

Split ridging is a traditional method for covering heavy trash gathered in the furrow bottoms. This technique can also be used to cover green manure. Farmers often express concern over the practice of leaving trash on the surface, saying it makes the farm dirty which is not good practice. It is evident that many extension workers have been taught to encourage clean fields.

### 7.2.3 Inter-cropping and cover cropping

Inter-cropping is a popular practice in the LAMP/SCAPA programme area where it is an essential component of the conservation tillage message. The dominating inter-cropping systems are maize–beans and maize–pigeon peas. One can plant one row of maize and the next with pigeon peas or alternate maize and pigeon peas in the same row.

Cover crops like lablab, beans, cowpeas, velvet beans, pumpkins etc. can be under-sown with the maize or sorghum. These crops are drought resistant, have deep roots and can fix large quantities of nitrogen which increases soil fertility, and an extensive shoot which covers and protects the soil and suppresses weeds. These crops are used both for human and animal consumption.

Both inter-cropping and cover cropping can be practised successfully with the ripper/ridger.
7.2.4 Mulch tillage

Mulch tillage technology involves a group of practices such as mulch ripping, hoe planting into mulch, tine planting with a ripper with a planter attachment and direct seeding into mulch (using a stick or jab planter). A common definition requirement for this system is that a minimum of 30% crop residue is left protecting the soil surface throughout the year. The residue of the previous crop may be slashed (e.g. maize and cotton) and left on the surface. Residue stubble from small grains (e.g. wheat, barley, millet) may also be used. Apart from the initial land preparation the soil is not ploughed nor disced.

Mulch ripping is a minimum tillage technique in which the land is ripped along each crop row on mulched plots. Fertilisers and seed are placed along the ripped line. Tine planting is a system in which planting is done directly (by hoe) into mulch. This may be described as a zero tillage technique.

The requirement that at least 30% residue cover is left on the soil surface renders this group of tillage techniques unsuitable for areas where the residue cover is removed through burning, grazing or during harvesting.

7.2.5 No-till ridging and no-till tied ridging

This system was developed to provide an alternative conservation tillage method for areas where insufficient crop residues are available to successfully practice mulch tillage. The name is meant to indicate the incorporation of no-till principles into conventional ridging and is not strictly no tillage. Ridging is best done with a ripper/ridger.

The land is deep ripped or sub-soiled and ridged in the first year. Thereafter the land is not ploughed again but the permanent ridges are repaired and maintained. The ripper/ridger fits well into the no-till ridging system especially since it creates soil conditions that are necessary for good water infiltration, and provides a system for complementary mechanical weeding. In less permeable soils, this technique can be incorporated with tied ridging (no-till tied ridging). Sometimes ties are built only in depressions in the field as protection against runoff breakthrough during heavy rains.

An important feature with tied ridging (based on the combination of ploughing and ridging or ridging with a plough) is that ridges are drawn across the slope at a gradient up to 1%. This allows the furrows between the ridges to drain in high rainfall years, while a maximum amount of rainfall is stored behind the ties in drought years. A tied ridging system based on the ripper ridger has superior infiltration capacity. One can follow the contour line without gradients, providing the ties are a bit lower than the ridges. The situation might be different on shallow and/or more impermeable soils. In this special case a slight gradient is recommended. Generally, it is safe to make the ridges along the contour line for semi-arid areas. The crop is normally planted on top of the ridge, although this may also be done on the side of the ridges or in the furrows in drought-prone areas.

A distinct advantage of the system is that all major operations can be carried out with the ripper/ridger alone (initial ripping and ridge formation and the primary weeding run). Ties can be made rapidly with a simple half-moon disc (cut from a plough disc or mouldboard) pulled by an ox or donkey.

The ripper/ridger system has been developed for faster ridging, ridge maintenance and weeding operations. Weeding is also possible when the crop is planted along the top of the ridges. Suitable planters that can be used for direct planting on ridges are available at the Tanganyika Farmers Association. This implement has attracted farmers’ interest and the demand is often higher than supply.

7.2.6 No-till strip cropping

This system was designed for smallscale farmers in Zimbabwe who cannot afford fertilisers, insecticides and herbicides. The method mimics nature’s principles of maximising plant biomass and diversity. It involves no tillage and optimises soil conditioning through high humus content, decayed plant roots and crop residues. It is also effective in weed suppression and integrated pest management.
The system involves a practice in which the entire rotation (normally practised by the farmer on separate lands) is laid out in narrow strips between each pair of contour edges (or other pairs of primary conservation works). Strips of densely planted crops (e.g. millet, fodder, sugar beans, soya beans) are placed between strips of wide-spaced row crops. These wide-spaced crops act as erosion and runoff buffer strips. The only soil disturbance is minimum strip tillage necessary for planting the seed. Fertility is provided to the cash crops only, often through the addition of compost. The system results in improved soil structure, which ensures maximum availability of nutrients and moisture. Wide-spaced row crops (e.g. maize) are planted to cover crops (e.g. pumpkin, lablab, cowpeas) to suppress weeds, increase diversity and reduce risks. Plant biomass is maximised through under-planting and by maximising planting densities. Pests are controlled through the plant diversity and optimal plant health backed up by natural methods of pest control.

7.3 Ripper/ridger conservation tillage systems

7.3.1 The ridge

The ripper/ridger is used to form furrows and/or ridges where crops are planted. New ridges can be built every year or the old ones can be repaired (hilled-up) each season. Where they are repaired, the ridges are permanent with the old crop roots left intact in the soil. These old roots form large macro-pores and good crop-growing conditions. It is recommended to make a planting furrow on top of the old ridge to ensure good crop establishment. Ridges form corrugation on the surface of the field, which improve rainwater management. The tops of ridges drain water, which then collects in the ditches where it infiltrates into the soil. The infiltration rate is closely linked with the extent of macro-pores, any compact layer or ploughpan, at the surface or below. Ridges formed by a standard ridger on top of a ploughpan can break easily due to poor water infiltration. The ripper tine should crack the pan and deepen the bottom of the furrow to form a large number of new macro-pores, which improves water infiltration. The deepening of the furrow bottom increases with weeding and ridging operations. Chopped stubble mulch, such as maize stover, placed at the furrow bottom increases infiltration rate and surface water holding capacity and prevents sealing of the furrows.

If rainfall intensity is higher than infiltration the excess water may either run along the ridges (off the field), or is held back by ridge ties or stubble mulch to be conserved for crop use (see Figure 6.15 in the previous chapter).

Gullying can occur when contour ridges are overtopped with rainwater at depression points or by water running out of the end of ridges that are not quite on the contour. This is especially the case on previously poorly ploughed and uneven fields, where ridges have been formed on top of ploughpans. Ridge marking without pegging often results in incorrectly designed (non-contour) ridges.

Tie-ridges are small cross-ridges linking the crop ridges every 3–4 m along the furrow. Their placing should alternate to strengthen the construction. Tying should be made in such a way that the ties are slightly lower than the main ridge. Such ties help to stop the accumulation of water moving sideways along ridge bottoms and consequent overtopping the ridges at low spots. Tie ridging is essential where ridges are only roughly across the slope (where contours have not been surveyed). This can be done by smallholders without any technical assistance.

If tie ridging is not done over the whole field, several cross ties are essential wherever small depressions occur along the contour. If made before the first heavy rains tie-ridges conserve the early rainfall, allowing the water to infiltrate and thereby benefit the crop. This is especially appropriate where the rains are erratic or unreliable. Crossed ties should be maintained until a full crop cover is achieved. To prevent breaking ridges built across the slope they must be at least 25 cm high when fresh and 20 cm high after the soil has settled. Ridges must drain into the contour channel or waterways. Ridges and ties must be rebuilt immediately if water flows over them to avoid gully formation.
It is essential to aim at an even distribution of water on the land surface. This is:

- For maximum water infiltration and supply of crop water
- To reduce water losses
- To prevent waterlogging
- To establish a uniform crop stand
- To minimise the erosive forces of running water.

Corrugation of a field with ridges formed by a ripper/ridger along the contour is an excellent method for achieving the optimum water distribution in semi-arid areas.

Crops may be planted on the ridge, in a furrow on top of the ridge, at the side of the ridge or in the channel between ridges, depending on soil, climate and crop requirements. Crops can also be planted in single rows or in multiple rows along the ridges. The width and length of ridges have to suit the soil and crop requirements. The ripper/ridger can be adjusted to produce ridges to the required dimensions and shape.

The term ridge planting refers to the practice of planting a crop on top of a ridge, while furrow planting occurs when sowing is done in the furrow between the ridges. Distinction can also be made between tied ridges and tied furrows. Tied furrows are used in very dry areas where rainwater harvesting is essential.

### 7.3.2 Advantages and disadvantages of no-till tied ridging

Table 7.2 summarises the Zimbabwean experience of no-till tied ridging (Nyagumbo, 1998). The recommended system for establishing a no-till tied ridge is deep ploughing followed by ridging with a standard ridger. In subsequent seasons, the old ridges are repaired (hilled up), either by a plough or standard ridger.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduces soil losses and runoff to sustainable level</td>
<td>Reduced moisture on the raised ridges</td>
</tr>
<tr>
<td>Applicable to a large range of soil types but is more effective in clayey soils</td>
<td>Initial labour requirements during first year can be high</td>
</tr>
<tr>
<td>Re-ridging eases weeding</td>
<td>Ridges have to be pegged by trained personnel</td>
</tr>
<tr>
<td>Stabilises soil structure</td>
<td>Suffers from wide daily (diurnal) temperature fluctuations</td>
</tr>
<tr>
<td>Rooting depth in shallow soils is increased</td>
<td>Susceptible to emergence problems</td>
</tr>
<tr>
<td>Effective in soils prone to seasonal waterlogging (improved aeration)</td>
<td></td>
</tr>
<tr>
<td>Higher or sustained yields obtainable</td>
<td></td>
</tr>
<tr>
<td>Suitable for yields with little or no-mulch</td>
<td></td>
</tr>
</tbody>
</table>


**Comments on disadvantages:**

- Poor germination and/or low survival rate is a common problem when planting on top of a ridge under dry conditions. A good method to overcome this problem is to split the upper part of the ridge with a ripper fitted with the short wings and the rudder for precision work if available (Figure 7.6). The new furrow ensures a good water supply in the centre of the ridge and good emergence conditions (as about 25% of the rainwater would be guided towards the emerging plants). Indeed, optimal conditions will be created for a deep and vigorous root system, which can fully utilise the harvested rainwater in the soil.

As pointed out earlier, there is a risk of ploughpan formation under the ridge system when the plough or standard ridge is used. This reduces the potential to achieve good conditions for crop growth. The ripper/ridger combination has the potential of reducing these disadvantages of the plough and standard ridger.
Figure 7.6 Planting in furrows on top of a ridge.

- The temperature fluctuation in the ridge is a problem for young and sensitive plants. The splitting of the top of the ridge and planting in the new furrow bottom will reduce the temperature variation and minimise evaporation losses.

- The splitting operation of the planting furrow will do little harm to the soil structure but create an optimum seedbed for the plant. Other advantages are early and effective weeding close to the plant and the possibility of applying fertiliser and farmyard manure for the desired plants. The planting furrow is then closed by the hilling up and weeding operations when the plant has reached a minimum height of 10–20 cm.

- The moisture stress on crops with shallow root systems on a raised ridge is mainly a problem of ridges on top of a ploughpan with heavy evaporation losses. Eliminating the ploughpan problem enables the crop roots to reach the water deep in the soil. It is possible to train the roots to look for water down in the soil by breaking any impeding soil layers beneath the surface.

- A 75-cm wide ridge is less sensitive to water stress in the centre of the ridge compared to a 90 cm ridge. The 15-cm difference can mean much for a young emerging plant facing a potential water shortage.

- The problem with heavy labour requirement during the first year is minimal if a combined ripper/ridger system is used to establish the no-till tied ridging system.

- Occasional split ridging (moving the ridge half a row in width) might be required to control heavy weeds. The benefits of weed control will most likely outweigh the disadvantages of increased tillage.

- It is evident that the disadvantages listed can be rectified by simple technical measures with a ripper/ridger system.

Farmers in Zimbabwe have already started to split the ridge using a simple ripper before planting with good results. There are also suggestions to lower the ridges to avoid water stress, or to plant on flat land and construct the ridges later as a weed controlling measure.

It is apparent that farmers work hard at improving the conservation tillage techniques and that they want a more flexible system. Their efforts would be more effective if they had the ripper/ridger, since this implement solves many of their problems. However, the adoption rate of the no-till tied ridging practice is estimated to be less than 1% in Zimbabwe. The reasons given for this low adoption include lack of awareness, unavailability of implements and incompatibility with current practices that the farmer is used to. Poor emergence has also been attributed as a major problem with tied ridging.

The experience of the dryland farming in the LAMP/SCAPA favours a flexible conservation tillage system.
Theoretically, the improved no-till tied ridging system, based on the ripper/ridger, appears to be the best option in the dominating agropastoralist/mixed farming areas.

### 7.4 Soil and water conservation using the ripper/ridger

#### 7.4.1 Introduction

Many of the farmers in the LAMP area do not practise any soil conservation measures. The rapid degradation of soils and accompanying decline in crop yields calls for a simple system to eliminate or reduce these losses. Measures that would reduce these soil and water losses may include:

- Ploughing combined with hand dug and grass stabilised *fanya juu* structures
- Ripping/ridging across the slopes
- Contour ridging with ripper/ridger
- No-till tied ridging with ripper/ridger

The objective of this section is to draw attention to the advantages of a combined conservation tillage and soil and water conservation approach. This report refers to the SCAPA manual *Soil Conservation in Arusha Region, Tanzania* (Assmo 1994) when discussing layout of contour bunds like *fanya juu* and *fanya chini*, storm drains, waterways and terracing. It looks into how to improve soil and water conservation through better tillage practices, concentrating on slopes up to 12% which involves the large majority of land in the SCAPA area. It is recognised, however, that the ripper/ridger technique produces acceptable results even on slopes of up to 15%. Preliminary findings of using the ripper/ridger technique in higher potential areas (in Arumeru) on heavy slopes indicate that the technique is appropriate when combined with good soil conservation practices.

An important aspect to be considered when discussing soil and water conservation strategy is the distribution of land in the programme area. Given a farmstead of half acre (*shamba la nyumbani*) and the farmland (*shamba la mbali*) situated some half to several kilometres away, it is often observed that the management level on the *shamba la nyumbani* is high while that of the *shamba la mbali* (which is often exposed to intensive post-harvest grazing) is low. Thus, one often applies different strategies on different types of land. For example, farmers will hardly construct hand-dug, grass stabilised contour bunds on the farmland when such structures become destroyed every year by herds of grazing livestock. Furthermore, the village policy on the use of crop residue and post-harvest grazing in agropastoralist areas is a crucial factor, which must be looked at seriously.

#### 7.4.2 Layout of ridges

The purpose of this section is to provide techniques for proper layout of ridges along the contour to avoid runoff and ensure safe drainage.

![Fig 7.7 Marking contour lines using the water level](image-url)
**Marking contour lines with the line level**

Contour lines are horizontal lines across the slope joining points of the same elevation. Contour lines are used to mark out conservation measures and/or ridges, which have to be level. Figure 7.7 shows the setting up of the line level.

The following items are needed:

- Water/spirit-level
- Thin but strong rope, 11 m
- Wooden poles, 1.5 m long, marked every 10 cm
- Measuring tape
- Pegs for marking the ground

Some three or four people are needed to survey a level line and to mark it on the ground.

Preparation: Attach each end of the thin rope to a wooden pole so that exactly 10 m of rope is between the poles. Check the length regularly. Mark the middle of the rope at 5 m with a knot. Hang the small water/spirit-level in the middle of the rope.

Marking contour lines: Proceed along the slope as shown in Figure 7.8. Survey 10 m at a time, or 0.5 m (half the rope length) in difficult topography.

![Figure 7.8 Using the line level.](image)

Make sure the string is taut and that both poles are upright. Put a peg at the foot of the pole, marking the starting point. Move the other pole up or down the slope until the bubble of the spirit level shows the string is level. Mark out with a peg where the second pole is standing. Repeat the procedure across the slope to mark out the contour line.

**Marking graded lines with the line level**

Graded lines are marks across the slope with small lateral gradient. They are used to lay out conservation structures, such as ridges, which are graded to drain excess water or for irrigation channels.

![Figure 7.9 Setting up line level for graded lines of 1%](image)
Preparation: For lining out 1% graded measures, the line level also uses a difference of 1% over 10 m length. That means that the rope is fixed on the poles with 10 cm difference (Figure 7.9).

Marking 1% graded lines on the ground: Start marking at the waterway or river and proceed up the slope (1%). The water should flow towards you. Always use the pole with the rope fixed higher up, nearer the waterway and the people with the rope fixed at 1 m, farther away (Figure 7.10). If you want a 0.5% slope the higher rope should be fixed at 1.05 m.

Figure 7.10 Using line level for graded lines of 1%

Adjustment of peg positions
It is often necessary to smoothen a pegged line before marking it out with a ripper or a plough. This smoothening process is carried out in the same way as plotting the best-fit curve of scattered points on a graph (Figure 7.11).

Figure 7.11 A peg line

7.4.3 Construction of contour marker ridges
The influence of land slope becomes less important in a cropping system based on properly designed conservation tillage practice. Ridges constructed along the contour drains runoff into safe channels. Hence, slope is more a concern with flat land cultivation practices, especially under the traditional ploughing procedure. Surface seals (crusts) and ploughpans, which all restrict infiltration, magnify the effects of slope. Indeed, the problem of runoff can be almost eliminated using a proper conservation tillage system. Ripping and ridging ensure high infiltration. Stubble mulching and tied ridging also eliminate runoff, except under extreme weather and soil conditions. However, if a tillage system can cope with up to 150 mm rain within 24 hours without significant runoff, then that system can justifiably be described as a highly safe and effective cultivation practice.

Contour marker ridges are constructed to guide the ridge system and provide protection against erosion. In a soil and water conservation system designed to fit a conservation tillage technique one can achieve both safety and high productivity without heavy inputs of labour and/or machinery.

Contour crop ridging is essential for all slopes above about 2% (1 m rise for 50 m up the slope). All tillage operations should be carried out on the contour. Ridges that do not follow the contour pose the danger of accumulating rain water at low spots and depressions especially during heavy storms. The accumulated water may break through the ridges and form rills and gullies. Tied ridging will go a long way to reduce
these problems. Ripping and ridging can also be practised successfully on flat land, in which case there is no reason for contour operations. A combination of contour planting ridges (formed by a ripper/ridger) and tie ridging gives almost 100% control of runoff and erosion on slopes of up to 15%.

When marking a contour, pegging is done to enable farmers to know their position. Pegging may be done about every 30 m down a gentle slope (2% to 7%), and every 20 m apart on steeper slopes (7% to 15%). Extension workers in Tanzania are now equipped with line levels for laying out contour marks. Enterprising farmers can also peg their own contours using an A frame or a line level from the Village Soil Conservation Committee or Department of Agriculture.

The first marker line should be pegged somewhere near the top of the field. The lines of pegs are adjusted by moving a short distance to give smoother lines. Usually the top contour bund will have to function as a storm drain. It is therefore essential to ensure that it is properly designed and constructed.

The starting point for ox-mechanised construction of a contour marker ridge is making a furrow along the pegged line. The ripper/ridger can be used. The oxen should be trained to follow a leader, who in turn follows the pegged line. This ensures correct positioning of the opening furrow.

The next step is closing the furrow to form a ridge. Figure 7.12 describes three steps followed when making a contour marker ridge with a ripper/ridger.

Step 1. Make a furrow using a ripper/ridger with a yoke whose $D_{yoke} = 150$ cm.

Step 2. Make a ridge: When turning the leader walks 37.5 cm on the left side of the centre of the opening furrow (1). Usually, it is at the edge of the soil pushed aside with the ripper/ridger ripper.

Step 3. Make a ridge: On the return, the ox on the right side follows the previous furrow (2). While doing so there will be a ridge with a width of 75 cm.

If a bigger ridge is desired, one can make another turn and deepen the furrows. In this way more soil is thrown on top of the ridge.

The ripper/ridger needs to be complemented with the plough for building larger permanent contour bunds. Figure 7.13 illustrates the process of enlarging a ridge using a plough. A hard soil can be broken up by the ripper and then scoped up with the plough. The essential question is the ability to make new contour bunds or restore old ones before the rains. As little time as possible should be wasted for this operation at the onset of the rain.
Figure 7.13 Construction of larger contour marker ridge with mouldboard plough.

If appropriately constructed, ridges conserve rainwater and safely drain the excess as runoff. The contour bund acts as an extra protection in case the ridge breaks through. The bund is formed as a combination of *fanya juu* and *fanya chini* operations. An advantage with this system is that minimum land is lost.

Another way of reinforcing the ridge is to plant a grass (such as vetiver grass) in the opening furrow. When the grass has rooted one can close the furrow and start the hilling-up operation. This will create a strong, durable marker ridge, which takes up a minimum area for soil conservation. The advantage of using vetiver is that cattle do not like it (except during adverse conditions) and so it will thrive and provide protection to the ridge.

If Napier grass is desired, one can lay the stem in line in the bottom of the furrow and cover it using the ripper/ridger. Shoots will then develop from the nodes on the stem. It is possible to get a thick and even stand of Napier grass using this method.

### 7.4.4 Effects of slope

Grading of ridges and contour bunds is complicated and there are different schools of thoughts. One school proposes that there should be no gradient when constructing tied ridges, while another advocates gradients of about 1% to ensure safe runoff during heavy rains. It must be recognised that the latter recommendation is based on using a combination of ploughing and standard ridgers and that the situation will be different with the ripper/ridger system advocated in this report. There is no need for a gradient in semi-arid areas if a ripper/ridger is used to form the ridges.

However, a safe compromise is a gradient of 0.5% particularly in areas with heavy soils with poor infiltration properties combined with heavy rains. When ripping and planting on a contoured evenly sloped field it is appropriate to start with the top contour, establishing parallel lines, and move down to the bottom contour. This procedure should also be followed when ridging.

On gentler slopes (up to 6–7%): A suitable perennial grass should be sown to strengthen the contour bunds against breakthrough in extreme storms. As stated earlier, vetiver grass is a good choice where grazing by livestock is likely to be a problem. Drought-resistant
crops, like pigeon peas, may also be used, as they have certain ridge stabilising effects. If seeds for stabilising grass/plants are not available, the marker ridges should be left unweeded (except for removing noxious weeds) to provide some natural grass cover.

On steeper slopes (7–15%, or over 1 m vertical rise for every 15 m up the slope): The marker ridges should be built up into one larger sweet potato-type ridge or contour bund. This bund should extend across the whole field if possible, or at least in low spots where water is likely to build-up and break through. Stabilisation is more important on this slope and rebuilding is required every year if needed.

7.4.5 Irregular slopes

Irregular slopes commonly occur when distances between the crest roads and the waterways are long and where the land has been contoured and minor drainage lines ignored. It is important to avoid the ponding at the lower parts. Tied ridging is the appropriate means of minimising this problem (Figure 7.14).

In the case where contours converge and diverge along their length, the procedure is to set out the ridges so that they enter the lower channel in the direction of flow and not against it. This is essential in areas of heavy runoff where tie breakthrough is possible. The string line method (described below) is used to mark a master ridge, which guides the construction of the other ridges in the desired direction. The intention is to follow the master ridge, both up-slopes and down-slopes, until the area is covered between the ridges. The string line ensures two things:

i) Where contours converge towards the waterway, all ridges spill into the waterway in the direction of the flow.

ii) Where the contours diverge towards the waterway, ridges run parallel to the bottom contour (Figure 7.15).

The master ridge technique is essential in soils with poor infiltration or where tied ridging is not practised.

The string line method

The string line method of making a master ridge requires three people, a ball of string and a supply of wooden pegs. The procedure, which is illustrated in Figure 7.16, is described below.

1. Start at the highest point of the contour and work towards the discharge end. One person must be in the channel of the top contour and one person in the channel of the lower contour. They hold the string firmly between them.

2. A large knot (or piece of material) is tied in the string, about 1 m below the top contour ridge. The knot must be large enough to be seen clearly.

3. The team walks along the contour channels for an agreed distance of about 10–20 paces, followed by the third person who puts in a peg behind the knot each time they stop.
4. When the tension on the string becomes slack (as the contours converge) the man on the top contour holds tightly to his end of the string, while the person on the lower contours reels in the slack.

5. When the string becomes too short because the contours are diverging, the person on the lower contour holds on to his end of the string, while the person on the top contour lets out the required length of string.

6. It is important to keep the string at right angles to the contour when reeling in or letting out string and to keep the tension constant.

7. Continue until all the pegs necessary to mark the master furrow have been put in from the crest to the waterway.

Rule: Top contour person lets string out; lower contour person reels string in.

If this rule is followed, the master ridge will be parallel to the top contour when the contours converge, and parallel to the lower contour when the contours diverge.

7.4.6 Instructions when ripping/ridging

Direction of ridges must be maintained if an obstruction is met in the field. Lift the implement and then start the ridge on the other side of the obstruction.

Water often collects where a ridge meets an anthill or rock outcrop because these obstructions commonly form islands of higher ground. This can be avoided by stopping the ridges a few metres before the obstruction and leaving a narrow grass strip between the ends of the ridges and the obstruction (Figure 7.17). The water from the ridges is discharged on to the grass strip and runs down into the contour channel below. Soil is conserved when the contour channel/bund is brought as close as possible to the lower side of the obstruction. Ties are also effective in checking the water flow. If the obstruction is an anthill, the most satisfactory long-term solution is to remove it.

7.4.7 Opening up new fields

The erosion hazard is closely linked to the size of a field, especially if the land is sloped. Long slopes gather more runoff than short ones. It is, therefore, important to avoid long, sloping fields without waterways to drain runoff water. This is particularly important where the ploughing technique dominates, as heavy runoff can occur on almost flat land after a relatively small shower.

The recommendation in the Eastern Province in Zambia is that newly cleared fields should be less than 2 ha in size. They should be oblong in shape with the long side aligned on the contour (e.g. 200 m along the contour and 50 m down the slope). Around each arable field the natural vegetation should be left undisturbed for as much as 30 m if possible. These strips of vegetation help to protect the arable field by controlling runoff from further uphill. These recommendations are based on a ploughing and ridging technique on slopes of up to 12%. These guidelines effectively reduce the problems caused by ploughing. However, such elaborate requirements might not be necessary with a conservation tillage system based on the ripper/ridger, which minimises runoff. If conservation tillage is the preferred management system, even larger parcels of land may be cultivated. However, the principle of leaving 30 m undisturbed around the field should be adhered to if land is available.
Where land is scarce or where overgrazing is a problem on hilly landscapes, it is recommended that storm drains be constructed to control uphill runoff. Waterways must also be made along the sides to direct any runoff emerging from the field. Proper land use planning is essential.

7.4.8 Crop establishment operation patterns

When changing from conventional to conservation tillage based on the ripper/ridger combination, there is need to assess the layout of the fields and how they have been tilled. The natural state of the area or the extent of previous work will all determine necessary preparations on a field. A simple land use plan is useful for designing a sustainable cropping system for each farm. It is usually enough with a sketch of the area starting with boundaries, roads/paths, individual field shapes, fences, direction of slope, depressions, obstacles, contour bunds etc. Of importance are also the neighbours’ land and how their fields affect your land. This simple sketch will give a farmer a good perception of the actual situation and what to do. Figure 7.18 shows an example of a simple lay out of a farm.

The sketch map can then be complemented by text on the needs of stumping, filling up holes, identifying depressions, repairs of gullies etc. Furthermore, it is a good instrument for discussing the effects of ploughing and planning improvements like conservation tillage and soil conservation measures.

![Figure 7.18 Simple sketch of a farmer's fields](image-url)
Two considerations must be made when planning a crop establishment operation patterns. These are:

- To identify the main direction of operation
- To select a suitable operation pattern.

Seedbed preparation and planting should follow the same pattern. In other words, those who are planting must (together with the draught animals) follow the same direction in which the land was worked during seedbed preparation.

### 7.4.9 Good crop husbandry

Up to 90% of the soil particles carried away by erosion are dislodged by raindrops falling on exposed soil and only 10% by the running water. This means that those measures which improve the plant and crop residue cover of the soil are very important. This may be achieved through good crop husbandry. Small differences in leaf cover of the soil can cause big differences in erosion. Hudson (1981) gives an example of two crops of maize at 10 weeks after planting, one at 24,000 plants per hectare covering 60% of the ground (i.e. 40% exposed), and one at 36,000 plants, covering 90% (10% exposed). The soil erosion recorded was proportional to the ground exposed and four times as great under the lower population.

It may be stated, therefore, that early crop establishment is important for conservation as well as for higher yields. Early planting minimises the length of time the bare and unprotected soil is exposed to the destructive impact of raindrops before crop cover is established.

Maize planted in 75 cm rows gives quicker ground cover than on 90–100 cm rows. Generally a closely planted well-fertilised maize crop at a high population (40,000 plants/ha) protects the soil better than wider spaced crops with little or no fertiliser. As a rule of thumb, where the expected maize yield is less than 3 t/ha the established crop provides only partial ground coverage.

The listed problems are particularly pronounced where ploughing is the main tillage operation. They will be greatly reduced with proper conservation tillage technique such as ripping, stubble mulching and tied-ridging. However, every simple means of increasing rainwater utilisation and cropping security should be used as a standard routine as it is the total effect which will determine the final result. A cover crop can be highly instrumental in filling the gap of crop coverage between the crop rows.
8  Sub-soiling for improved yields: The Babati experience

8.1  The productivity trend in crop production

In the 1980s, Babati District experienced a drastic reduction in crop yield. Maize yields dropped by more than half due mainly to soil degradation. The formerly virgin and fertile soils of Babati District turned to marginal soils within a decade. Farmers also complained of frequent droughts. Soil and environmental experts identified erosion caused by poor conservation measures, deforestation and overgrazing, as the main threats to the farming systems. The extension service listed poor demand for costly fertilisers and improved seeds as a serious bottleneck. Unfortunately, inappropriate tillage practices were not identified as a possible cause of decreasing crop yield.

Poor harvests and complete crop failure occurred frequently due to regular water stress caused by inadequate soil moisture. High risks and poor returns made farmers hesitant to use costly farm inputs such as improved seeds and chemical fertilisers. The prevailing tillage systems (involving ploughing the land 2–3 times before planting) could only secure meagre returns after some years in use.

Low crop yields were obtained in spite of fairly fertile soils and good average rainfall (794 mm) in Babati. This was a strong indicator of poor utilisation of the existing rains. This argument was further strengthened by heavy runoff, waterlogging and evaporation losses caused by poor rainwater infiltration into the soil. While these constraints were genuine problems that contributed to the negative crop development trends, a more consistent analysis showed that they were merely symptoms of bad land management practices rather than the real or key problems.

8.2  The effects of cultivation and grazing

Approximately 95% of the LAMP area is semi-arid with irregular rains. An extensive survey of the three Districts of Babati, Kiteto and Simanjiro in 1995 confirmed that the common cultivation and grazing practices were the main reasons for the poor soil conditions and subsequent low crop yields. Very few farmers used any soil conservation measures, except in some limited medium/high potential areas in Babati.

Surface crusts and plough pans were prevalent and highly instrumental in restricting rainwater infiltration, leading to runoff, erosion, waterlogging and shallow and drought sensitive cropping systems. The traditional method of cultivating ridges by hand has been used for centuries in the semi-arid LAMP area and has often produced enough food for the populace even under adverse conditions. However, being very labour intensive, it is often abandoned where there is easy access to virgin land and mechanised ploughing by oxen/tractors. Instead of ridging, flat land cultivation is taking over. This type of mechanised shifting cultivation is now rapidly changing large tracts of land into minimum yield potential areas.

Almost 90% of cultivated land was ploughed up and down the slopes, about 1 to 3 times per season. Most known negative effects of ploughing were clearly visible. It was therefore, concluded that ploughing must be a main cause of the severe soil deterioration and low and insecure crop yields. Erosion was mainly a consequence of the heavy runoff caused by the existing ploughing practice.

8.3  Erosion between contour bunds

An interesting feature in Babati District was the widespread sheet erosion between the contour bunds on ploughed fields, despite the soil conservation structure. It was evident that infiltration of water into the soil was impeded. Figure 8.1 shows a photograph of a ploughpan dug out from a ploughed field with soil conservation structures. The thin layer of fertile topsoil was washed down to the lower bunds. This was
clearly demonstrated by low crop yields at the top (upper) part and much better yield at the bottom part of the land between the contour bunds. The water accumulated at the lower bund and had to be drained off to avoid waterlogging. No doubt precious water and crop nutrients were lost even with the recommended soil conservation measures. The contour bunds increased cropping security, but they had less effect than expected on the overall grain crop yield on the ploughed flat sloping land between the bunds.

It was apparent that a basic principle of appropriate dryland farming (that of controlling runoff and conserving water where it hits the ground) had been overlooked. As much water as possible should infiltrate into the soil to be stored and subsequently absorbed by the crop roots, while the surplus infiltrates further down to the ground water. Another important reason of preventing runoff and to drain off water is that the crop nutrients available to the plant roots are dissolved in the soil water and runoff can effectively deplete a soil of its essential nutritive substances.

A cultivation system which holds the water and soil over the cropped surface and improves water infiltration and crop root development would consequently lead to reduced loss of water, nutrient and soil through erosion. It would increase yields and food security. No doubt, effects of common soil and water conservation practices could be greatly improved with better tillage practices, which enable rainwater to infiltrate at a higher rate.

8.4 Rain water utilisation

Rainwater utilisation in this manual is defined as yield per hectare per mm rain (kg/ha per mm). This is a useful measurement for cropping security and productivity under normal and dry weather conditions. Only 25% of the tilled land in Babati District was planted in the 1994/95 season when more than 50% of the total rain of 772 mm had fallen. This indicates a poor rainwater utilisation efficiency in the cropping systems. Almost all soil moisture was lost from the short rains (vuli season). A common practice is to plant crops throughout the rainy season to minimise the risk of crop failure due to drought periods at the expense of crop yield. In the drier areas cropping is practised only during the long rains (masika season).

During the late 1980s, rainwater utilisation rate went down to 1.5 kg maize/ha per mm. This low figure indicated a highly wasteful system of utilising the rains. It has been proved that it is possible to increase this figure by 3–4 times during most years with simple conservation tillage techniques and use of some farmyard manure. It is evident that improved rainwater utilisation must play a major role in the efforts of improving the land management practices.

8.5 Livestock and fodder

There are at least as many cattle as there are people in large parts of semi-arid Tanzania. Livestock production is defined according to mode of production. The following grouping applies to north-western Tanzania:

1. Pastoralists — live exclusively on livestock rearing in the rangeland.
2. Agropastoralists (extensive) — combine pastoralist mode of livestock rearing with some crop production.
3. Agropastoralists (intensive) — combine pastoralism with more sedative modes of livestock rearing, and more emphasis on crop production.
4. Mixed farmers (extensive) — combine extensive livestock and low input crop production within the village boundary.
5. Mixed farmers (intensive) — more intensive livestock and crop production in medium/high potential areas on owned land.
6. Agriculturists — crop production only.
The combination of groups 2 to 4 dominates in the semi-arid parts of Arusha area and is found in most villages. Free post-harvest grazing is a major source of fodder during the long dry season. It starts after the crop is harvested. The extensive trampling with hooves pulverises the soil surface creating conditions for surface sealing and heavy runoff. The combination of ploughing (flat land cultivation) and overgrazing makes the situation worse.

Post-harvest grazing can be devastating to soil conservation structures and, if manually constructed, it entails a heavy task of repairing them. The late-maturing pigeon peas delay the onset of post harvest grazing in the fields in which this crop is planted.

A very interesting observation in Kondoa District, which borders Kiteto, where ridging is the standard cultivation practice, was that the ridges remained effective even after intensive post-harvest grazing. The height of the ridges was reduced, but the land was still well corrugated. It appeared that the livestock followed the furrow bottom while grazing the crop residue. This means that the ridges could be easily reformed in the same place with proper implements. Where the ridges followed the contours, the damaging effect of intensive trampling such as runoff and erosion was greatly reduced. The same observation was also made in Singida District, where ridging by hand is a traditional cultivation practice.

To safeguard fodder for their animals, some farmers take their crop residue to the homestead. Farmers with zero-grazing units have started buying crop residue from other farmers for their dairy cows, because the grass production on contour bunds is insufficient. Approximately 11 acres (about 4.4 ha) of land with soil conservation bunds stabilised with selected grasses is required to feed one dairy cow in semi-arid areas (Tekie, 1997). That makes zero-grazing a possible alternative for the smaller high potential areas only, but hardly the solution in the dominating agropastoralist and extensive mixed farming areas. Lack of transport facilities particularly limits the scope of the cut-and-carry system.

Free post-harvest grazing is a very wasteful method of grazing, as more than 50% of the nutrients in the crop residue is lost to the livestock due to bleaching, trampling, breaking, mould, termites etc. With better post-harvest practices it is possible to triple the current feeding efficiency of crop residue.

Many farmers make more money from their traditional livestock than from their crops. This makes discussions on de-stocking and grazing a highly controversial issue which cannot be overlooked in efforts to increase the productivity of natural resources.

### 8.6 Inter-cropping and farmyard manure

During the 1990s, there was a positive crop yield trend in the Babati District. The maize production doubled from approximately 1,000 kg/ha to 2,000 kg/ha. Inter-cropping of maize with pigeon peas and maize with beans and the increased use of farmyard manure, are among the main reasons for this improvement. It is expected that a further but substantial increase will occur with the full implementation of the dry land farming/conservation tillage techniques.

Only a small part of the farmyard manure is recycled to the cropped land. Consequently, there is a great potential of increasing fertility through better use of existing organic matter. It is apparent that the large herd of livestock in the programme area can have a major impact on productivity of land if properly managed. Lack of farm transport is a serious constraint to the use of farmyard manure.
9 Adaptive research on conservation tillage systems: The Arusha and Arumeru experience

9.1 Background and rationale

The Soil Conservation and Agroforestry Programme (SCAPA), Arusha, has successfully built capacity and disseminated soil conservation and agroforestry practices for over a decade in Arusha and Arumeru Districts. Despite these years of erosion control, participatory assessments of farmers’ problems persistently identify low yields as a major problem in the area. Farmers and extension staff from both districts identify low soil moisture as the major contributing factor to poor crop yields. It is apparent that infiltration of rainwater into the soil is poor, leading to high runoff losses between the fanya chini terraces.

To address this problem SCAPA, in partnership with RELMA and LAMP, initiated an effort to introduce, test and design conservation tillage systems (through adaptive research) together with farmers. These on-farm trials have been running under varying conditions of rainfall, soil, slope and farming machinery since the short rains in 1998. The overall hypothesis of this study is that long-term crop yields and land productivity can be sustained and enhanced through cropping practices by abandoning the conventional plough, while introducing reduced tillage techniques (ripper, sub-soiler) and alternative land management practices (regarding weeding, mulching and timing of crop/land interventions).

9.2 The agro-ecological setting

Arusha and Arumeru Districts are in the north-eastern part of Tanzania (Arusha region). The two districts have three agro-ecological zones, highlands, midlands and the lowlands.

9.2.1 The highlands

This is a densely populated area with an average of 109 people per square kilometre. It has a higher agricultural potential than the other two agro-ecological zones. Its altitude ranges from 800–1400 m above sea level with an annual average of 800–1200 mm rainfall. Both traditional and conventional agroforestry systems are practised in this zone. The major crops in this area are coffee, bananas and some annual crops. Other crops grown are vegetables (tomatoes, cabbages and onions); maize (mostly hybrids) mixed with beans, pigeon peas and cowpeas. Livestock found in this region include cattle, goats and sheep, raised in a semi-intensive zero-grazing system. The main soil type is volcanic with some patches of red soils.

9.2.2 The midlands

This area is moderately populated with an altitude ranging from 500–800 m, above sea level, and an annual rainfall of 400–800 mm. Crops grown are the same as those found in the highlands. This area is, however, dominated by annual crops and less coffee and bananas. Another difference from the highland zone is that maize varieties grown are mainly composites, mixed with beans, pigeon peas and lablab (*Lablab purpureus*, earlier called *Dolichos lablab*). Livestock kept are similar to those kept in the highlands. The livestock system is semi-intensive.

The soils of the midlands are mainly alluvial deposits of a volcanic nature, originating from the slopes of Mount Meru. These soils have a high clay content, especially in the flatter areas, making them difficult to cultivate. They have swelling and cracking characteristics with changes in moisture content, and a low permeability that makes them prone to water logging which leads to crop failure. A hardpan in the upper part of the profile is mainly responsible for this phenomenon. The soils also disperse with rains and clog the pores, thus decreasing their permeability to rain water.
9.2.3 The lowlands

The lowlands are sparsely populated. The area lies at an average altitude of 500 m above sea level and has an average rainfall of 250–400 mm per annum. The rainfall distribution is unreliable. The main soils of the area are heavily compacted. Crops commonly grown are maize, beans, cassava, lablab and cassava. The livestock system is extensive, with large numbers of cattle, goats and sheep.

9.3 Location of trials

The demonstration trials are based in three villages located in all three agro-ecological zones found in Arusha and Arumeru Districts. Two sites, Ngorobob and Sakila villages, are in Arumeru while one site (Mkonoo village) is located in Arusha District. In Sakila, three farmers are involved, of whom one is located on the steep slopes which receive high rainfall (thereby cultivating during both the long and the short rains). The other two farms are located at a lower altitude (cultivating only during the long rains). In Ngorobob village, two farmers are involved. Their farms are in low potential areas. Mkonoo village has two low potential sites representing the lowlands. These farmers and sites were identified together with the respective farming communities.

9.4 Research approach

Farm demonstrations on conservation tillage were implemented as a collaboration venture between the technical extension staff and farmers. Farmers were actively involved in planning the trials and were also fully responsible for implementation and monitoring.

The conservation tillage initiative started with a planning workshop which was attended by the selected farmers. Problems in present land management were discussed. Participants were exposed to the concept of conservation tillage, which was completely new to them. Interest among the farmers developed steadily as a result of the match between their perceived problems (high runoff, poor infiltration, soil nutrient mining, hardpans) and the possible solutions offered by conservation tillage techniques. The farmers were then exposed to different experiences of conservation tillage around the world, and especially to different implements and techniques. The systems approach was presented and discussed. In this approach, conservation tillage was presented as more than a mere change in implement, but actually a change in how farming is carried out, including planting, weeding, fertilisation, mulching and timing of all operations.

The final step of the planning workshop was to design (as a group) a set of conservation tillage production systems to be tested. The farmers were very interested in being the leaders of designing relevant conservation tillage systems. The role of the extension officers and the RELMA group was to discuss layout and make experimental design which give comparable results (assuring a good comparison between conservation tillage and the present ploughing systems).

During the planning workshop, visits were made to the respective farmers’ fields to discuss layout and to start training oxen. Ox training is a crucial part of any conservation tillage demonstration because the oxen have to learn how to walk in straight lines.

All the fieldwork, from the setting up of trials to harvesting, was carried out by farmers and extension officers together.

A partnership contract was established between SCAPA and the farmers. In this contract the farmers agreed to carry out all farming activities and to be actively involved in the management and improvement of the practices. Other agreements were that:

1. A farmer would be committed to the research over a period of 3 years.
2. A farmer would be compensated for possible yield losses in the experimental plots (when compared to his/her traditional practices).
3. The role of SCAPA was to supervise the fieldwork, implement the new practices together with the farmers and document the results.

4. The role of RELMA role was to assist in the supervision. The stakeholders involved were thus the farmers in the three villages, extension staff from SCAPA, and RELMA and LAMP.

9.5 Tested conservation tillage systems

The demonstration trials agreed upon by all the stakeholders involved the following three production systems:

- Conservation tillage using ripping and/or sub-soiling (by animal or tractor)
- Conservation tillage using ripping and/or sub-soiling but skipping each 2nd planting row (to create a broadbed system where the inter-rows are used to harvest water).
- Conservation tillage using pitting (manual)
- Conventional tillage using mouldboard or disc plough (the traditional method)

The type of traction varied with the farmer. In Ngorobob, for example, farmers used hired tractors with disc ploughs for land preparation. In these circumstances tractors were used for sub-soiling (necessary due to the extremely hard ploughpan created by years and years of disc ploughing).

Below is a detailed outline of the different production systems tested.

9.5.1 Sub-soiler with ripper

Normal planting density (75 x 30 cm)

An initial sub-soiling is carried out before the rains, followed by the Magoye ripper, only in permanent planting lines (75 x 30 cm apart). No tillage is made between the lines.

Cultivation is carried out each year exactly on the same lines.

Manure and/or fertiliser are placed in the planting lines together with the seed. Intercropping is possible (and indeed encouraged) if it corresponds with the farmers’ practice (such as one row maize, next row beans, next row pigeon pea).

Intensified weeding pattern. Mulching is a necessity.

Sub-treatments

Oxen/tractor drawn implements

Manual weeding/draught drawn weeding implements (Magoye ripper with wings)

Cover crop/no cover crop.

Zero tillage

Manually dug sowing pits at the same planting density as usually practised. Pits dug with hand hoe, measuring 25–35 cm wide, 15 cm long and 18–20 cm deep (it is crucial to break through the ploughpan created by the plough).

Manure and fertiliser placed together with seeds. Mulch is necessary.

Sub-treatment

No cover crop.
9.5.2 Crop rotation and cover crops

Maize is the main crop grown in all the farms. Although the maize variety varies from season to season, in principle, the strategy is to use short-term varieties (like the 90-day Katumani composite variety) in the lowlands and in the highlands during the short rains (Sakila). Hybrid varieties are used during the long rain season (513 HB) in the highlands (Sakila).

There is variation at different sites on whether intercropping is practised and, if so, which crops are intercropped. The choice of crop for intercropping (a form of relay cropping) varies depending on the rainy season (long or short rains).

By agreement, the intercropping or cover-cropping system used on all farms was maize combined with lablab. In Sakila, during the short rains, maize was intercropped with cowpeas.

Weed management

Weeding is carried out manually, according to the traditional practices, in both the conservation tillage and ploughed systems. Cover cropping and mulching are used to suppress weeds.

Fertilisation

Both inorganic and organic fertilisers are used. The rates of phosphorus and nitrogen recommended for each area are applied using Minjingu rock phosphate and urea.

Application rates for Minjingu rock phosphate are given below:

<table>
<thead>
<tr>
<th>Treatment</th>
<th>No. of plants/ha</th>
<th>g of R/phosphate/seed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ripping</td>
<td>44,000</td>
<td>11</td>
</tr>
<tr>
<td>Broadbed</td>
<td>22,000</td>
<td>22</td>
</tr>
<tr>
<td>Pitting</td>
<td>31,250</td>
<td>15.5</td>
</tr>
<tr>
<td>Control</td>
<td>42,000</td>
<td>11.5</td>
</tr>
</tbody>
</table>

Nitrogen fertiliser (urea) is applied as a top dressing, at 30–50 cm height of plants.

9.5.3 Planting density for different treatments

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Planting density (No. of plants/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ripping</td>
<td>44,000</td>
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<tr>
<td>Pitting</td>
<td>31,250</td>
</tr>
<tr>
<td>Control</td>
<td>42,000</td>
</tr>
</tbody>
</table>

Manure

Each treatment receives 3 tonnes of farmyard manure per hectare. The manure originates from each individual farmer hence quality varies between sites and over time.

Table 9.1 Manure application methods for different production systems

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Application method</th>
<th>Method of cultivation amount to apply</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ripped/sub-soiled</td>
<td>In planting lines, i.e. ripped lines</td>
<td>Calculated for each planting line</td>
</tr>
<tr>
<td>Pitting</td>
<td>In pits</td>
<td>Calculated for each pit</td>
</tr>
<tr>
<td>Control</td>
<td>Broadcasting</td>
<td>Calculated for each plot</td>
</tr>
</tbody>
</table>
The amount of manure to apply on each plot, at each site, is calculated as follows:

1. Measure of the total area of the plot.
2. Calculate the manure per plot (corresponding to 3000 kg/ha)
3. For ripped/sub-soiled plots, estimate the number of lines per plot.
4. Average the figure obtained above to the nearest lower full number.
5. Divide the weight of manure per plot with the number of rows.
6. Weigh the manure using the bucket to get a common measure for application.

9.6 Harvest results for the long rains 1998

The harvest results were summarised and discussed in detail with the farmers. Figure 9.1 shows the grain yields in bags per acre for each plot/treatment (2 blocks or repetitions per farm). The reason of translating the grain weights into bags (90 kg bag) per acre is that this is the measure the farmers themselves use. In assessing the results all farmers agreed that the control yield, ranging from 3–7 bags/acre (675–1,575 kg/ha; except for Losiocky who harvested 10–11 bags/acre (2250–2475 kg/ha)) was representative of a reasonably good yield in the traditional system. Rainfall received during the long rains 1998 season varied greatly between sites (Figure 9.2), with the lowest amount (260–318 mm) being experienced in Ngorobob (the difference found between the two fields within Ngorobob village). Mkonoo received 387 mm and Sakila 679 mm of rainfall.

9.6.1 Julius’ farm

Until the 1998/99 season, and 5–10 years before, Julius was obtaining maize yields of 0.5–1 bag (100 kg) of grain per acre (about 250 kg/ha). He actually abandoned the field in 1997. The soil in his field was heavily compacted from the long use of oxen drawn mouldboard/disc plough tractor drawn implements. There was very low level of organic matter (indeed in some patches there was no organic matter at all). The field undulates as a result of long periods of tractor ploughing. Rills pass through the field and crusting was prominent.

This field was so compacted that tractor sub-soiling was carried out, using a 150 hp tractor with 1 m long times and the depth achieved was 35–40 cm deep. This was followed by animal drawn ripping to establish planting lines.

From the results, it is clear that sub-soiling had some effect, but the results are difficult to interpret due to severe patches of crusting which lead to water logging (which according to the farmer explains the poor performance of the ripper in block 1–7 bags/acre). The positive effect of fertiliser on traditional ploughing is, however, noticeable which probably indicates that nutrients were the primary limiting factor during the seasons.

9.6.2 Ngorsiolo’s farm

Animal drawn mouldboard ploughing has been the traditional practice on Ngorsiolo’s farm. The farm is well conserved with contour bunds on black soil. A ploughpan was visible and became a problem for root penetration and infiltration of rainfall. Before the construction of conservation structures, the farmer was harvesting 1–2 bags per acre (about 500 kg/ha). With soil conservation and application of farmyard manure, the yield increased to an average of 6–10 bags per acre (1350–2250 kg/ha).

The results show a stabilised and increased yield using both animal drawn ripper (yield range from 12–14 bags/acre (2700–3150 kg/ha) and pitting (12 bags/acre (2700 kg/ha)). Once again, fertiliser application using conventional ploughing gave reasonable results. The yield fell to 4–5 bags/acre (900–1125 kg/ha) with no nutrient application.
Figure 9.1  Grain yield in number of bags/acre of maize for each farmer and treatment for the long rains 1999. The two columns of bags represent the two blocks/repetitions in the experiment. The numbers on top of each column is the actual experienced number of bags. Ripp = Ripper, Ripp + CC = Ripper with cover crop, BB = broadbed ripped system, Pitting = manual pitting, C + FERT = traditional ploughing with fertilisation, C = traditional ploughing with no fertilisation.

Comments on Figure 9.1:
I verall, the ripper treatments resulted in increased and more uniform yields. Despite slightly lower yields, the farmers unanimously ranked pitting as the best production system, not because of the tilling effect, but due to the control it gives the farmer when it comes to spot application of fertilisers and manure. With pits, every hand-full of manure is used efficiently because it is placed just next to the seed. One of the farmers liked the broad-bed system, which performed poorly and was later eliminated from the experiment. However, the poor performance may have been because the overall rainfall was adequate, making the runoff in the inter-rows abundant.
Lengiyu opened up the land more than 10 years ago. His initial yield from the virgin land was about 15 bags/acre. However, production rapidly declined to 1–2 bags per acre (225–450 kg/ha). After the construction of contour bunds with application of farmyard manure, yield increased to 2–5 bags/acre (450–1125 kg/ha). More crops were harvested along the lower bunds than in the upper bunds. Soils are red, have very little organic matter and a hardpan of 30 cm deep.

Although the contour bunds reduced runoff substantially, the field was subjected to serious sheet runoff over many years, probably leaching the topsoil. This explains the overall low yields ranging from 3–6 bags/acre (675–1350 kg/ha) for all treatments except ripping. Ripper treatments resulted in grain yields of 7–14 bags/acre (1575–3150 kg/ha).

9.6.4 Losiocky’s farm

This field was ploughed by tractor (disc) and ox-drawn mouldboard for many years. In the 1995/96 period, the farmer harvested 5 bags of maize per acre, followed by 2 bags per acre the following year. The farm has red soils and is on a gentle slope with contour bunds at a distance of 10–15 m apart.

The farmer is gratified that the fertility lost through water runoff is minimal after the construction of contour bunds in his field. However, his field is mostly bare with no crop residue since he grazes animals after harvest. There is strong evidence of soil compaction at a depth of 10–15 cm.

Yields are high for all conservation tillage treatments and also in the fertilised ploughed plot.
9.6.5 Daniel's farm

Conventional ploughing was the usual practice for many years on this farm, with yields generally not exceeding 5 bags/acre (1125 kg/ha). The soil had a hardpan at 10–15 cm depth. The field was bare of any crop residue, but weeds were prominent in the whole field. Detection of the hardpan apart from digging is evident by uprooting any taproot weed. The roots are only 6 cm from the top. The roots are thick like a nodule, and change directions laterally to skip the hardpan. The first two contour bunds are less than 10 m wide while the third is more than 10 m wide.

The yields were very stable for all fertilised treatments with the highest yields experienced with the ripper (19–20 bags/acre; 4275–4500 kg/ha).

9.6.6 Noel's farm

Noel cultivates on narrow well-conserved terraces on a steep (35%) land. The soil is fertile, but he has a problem with an uneven crop stand along the width of each terrace. The maize looks much better at the lower part of the terrace than at the upper side. This is a sign of soil movement due to runoff within each terrace.

Noel himself credits the higher yields using the ripper to zero runoff within the terrace, resulting in a uniform height of the crop along the full width of the terrace. The control treatment (conventional system) yields 3–7 bags/acre (675–1575 kg/ha; compared with 20–26 bags/acre (4500–5850 kg/ha) for the ripper treatments), which were within the range Noel normally obtained.
References


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