HDI-III

Environmentally Sustainable Food Security and
Micro Income Opportunities in the Dry Zone
MYA/99/006

GUIDELINES ON SOIL AND WATER CONSERVATION FOR THE MYANMAR DRY ZONE

REVISED VERSION

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FOR
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FOREWORD

The Dry Zone of Myanmar is characterised by shallow soils, low and uneven rainfall distribution, and a high degree of soil erosion, all of which result in severe land degradation and an augmenting rate of desertification. Ways are needed to address the increasing occurrence of drought as a consequence of this process, for the benefit of the inhabitants of the area as well as for the country at large. Rehabilitating and reclaiming land in the Dry Zone should be viewed as a priority by all stakeholders involved in rural development.

Soil and water conservation are the principal measures that need to be undertaken to reduce the increasing pressure on scarce land resources, enhance productivity, generate employment and prevent environmental degradation. A conservation based strategy has been adopted as the core to land rehabilitation around which all efforts aimed at developing the Dry Zone are tailored. This strategy lies at the root of the UNDP funded Dry Zone Project [1].

The project implementation strategy is guided by a number of key principles. These are: integration, consultation, a planned spatial approach, decentralization and flexibility, all of which are critical for the development of semi-arid areas. Adherence to these principles requires:

- Integrating sectors, techniques and actions and incorporating traditional experience.
- Participation of the people through continuous consultation within and between communities to enable them to take decisions, organise and manage their work and resolve differences and conflicts

Zone townships (Kyaukpadaung, Magway and Chaung U), the scope of the guideline is broader describing the nature of the problems and the potentials throughout the area.

This is the Third Edition of the manual and as such reflects the accumulated experience of the project in the Dry Zone since the beginning of the second phase of HDI in 1997. The guideline has been prepared from the field experience gained during the testing and implementation of the soil and water conservation measures introduced over the period. Most of the measures, described in the guideline originate from observations made of traditional soil and water conservation measures widely practised in several Dry Zone locations. The guideline, however, also includes measures applied from other areas of the world which are of relevance to the Myanmar conditions.

After four years of implementation the results and performance of the measures have been most promising and pave the way for achieving substantial progress in rehabilitating and reclaiming degraded lands, improving food security and reducing poverty. Most of the techniques and recommendations included in the first two drafts of the guideline are still valid although some slight technical modifications have been required in some areas.

The subject of Soil and Water Conservation in Myanmar should be regarded as a science in its infancy and seen as part of a dynamic process that calls for additional testing and close monitoring and evaluation of the different measures at regular intervals. It is, moreover, an on-going effort, aimed at refining and modifying techniques over time and generating new ideas.

As a final recognition of intention, it should be pointed out that these guidelines have been prepared for the benefit of all technicians committed to rehabilitating the Dry Zone with the challenge of ensuring food security and enhancing the income of the rural poor.

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MYA/99/006

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Volli Carucci

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INTRODUCTION

1. GENERAL

Land degradation in the Myanmar Dry Zone is becoming a matter of serious concern for its negative implications on the livelihood of the rural population and the environment from which they largely depend. An ever increasing population in combination with unfriendly climatic conditions triggers the rapid misuse of the land and over-exploitation of natural resources. As a consequence, soil erosion by water and by wind and the progressive removal of the vegetative cover are becoming common features observable in most parts of the Dry Zone. Therefore, land degradation is a most dangerous form of negative ecological process, taking gradually irreversible forms as the process advances and accelerates.

In the Dry Zone soil erosion is high, particularly in the form of water erosion during the rainy season. Rills, gullies and rivers full of sediments show that a considerable amount of soil is carried away, mainly during the destructive intense storms which characterize dry zones rainfall patterns. Most of erosion occurs on the cultivated land in the form of sheet, rill and often gully erosion, rapidly curtailing yields and income levels as a consequence of it. However, it also occurs on pastures, marginal lands and forest areas which are not properly managed. The overall phenomenon is described as a vicious cycle spiralling downwards towards desertification, poverty and starvation.

Traditional measures, though valuable and an essential source of inspiration and reference, are generally not sufficient to counterbalance the pace of the process and need to be improved, consolidated and supplemented by additional technologies.

The development of effective and farmer-led technological packages should be seen within a diversified social and bio-physical context, made of different farming systems and levels of land degradation interacting within defined spatial units.

In this regard, the scope of this manual is to present a set of measures which should not be viewed in isolation but as part of an integrated effort able to tackle the land degradation problems related to a given territorial unit and its farming system.

Within this context, the overall process of land degradation in the Dry Zone, i.e. its causes and effects, its forms and agents, and a wide range of possible remedies and cures would be explained in the following chapters.

2. HOW TO USE THE GUIDELINES

This document is divided into five parts or chapters. The parts are linked one another and are meant to guide field technicians to understand the dynamics of the degradation and erosion processes and to select the soil and water conservation measures most suitable for their area. It is important to emphasize that the measures described in the guideline are not exhaustive and that a lot more research and experimentation is still required. However, the guidelines offer a starting point, which will be of value to initiate a learning process that addresses land degradation issues and problems affecting the Myanmar Dry Zone.

Part I: Profile of Arid and Semi-arid Regions

This part explains the climatic and bio-physical context of dry lands and the relationships between land degradation, food insecurity and poverty. As a result, the entire set of social and environmental implications are mentioned and analysed from the perspective of Myanmar Dry Zone conditions. It is very important that field technicians learn to recognize these factors since they influence the choice of measures and their acceptance, sustainability and replicability at the land user level.

Part II: The Erosion Process, Agents and Effects

An essential element for the identification of suitable technological packages able to arrest land degradation and increase and sustain production levels is the understanding and analysis of the erosion process occurring in the Dry Zone. Erosion, mainly by water and wind is the utmost visible manifestation of land degradation. Some forms of erosion are easy to depict such as gullies and rills, others are less evident but for that reason not less insidious and detrimental such as sheet erosion and wind erosion.

Erosion and its consequences on fertility and production levels, water regimes, vegetation cover and biomass production, bio-diversity and sedimentation have to be understood and measured in order to develop appropriate strategies and techniques for soil and water conservation. Besides, an accurate analysis of the erosion process would allow to determine the connections and mutual relationships between land uses, soil types, landscape units and farming practices, and thus the integration requirements (technical, social, spatial) necessary to ensure an effective and comprehensive soil and water conservation.

In part II, the erosion process is described in detail, including on-site and off-site effects of erosion effects, and empirical methods of erosion measurement.

Part III: Technical elements effecting the design and implementation of soil and water conservation measures

This part is developed to provide field technicians with a basic set of key technical elements which should be taken into consideration in order to identify, select, design and implement soil and water conservation measures in the Dry Zone. In other words, Part III is to be considered as an information kit on technical parameters and indicators useful to appraise. diagnose and analyse some of the bio-physical characteristics of a given area which are not normally included (or elaborated) as part of the surveys undertaken by a grass-root level participatory planning exercise.

This includes the analysis of rainfall and runoff, the plant water requirements, the soil type and the landscape conditions in the form of a land classification system.

Regarding the soil and landscape conditions, an indicative land classification system has been developed for use in soil and water conservation. The intention is to facilitate the identification of the main constraints or limiting factors affecting the land use and thus assist in the selection of a range of soil and water conservation measures which could be of relevance within such range of constraints. The system should be used flexibly and amended regularly based on the experience gained and field performance and impact of the different measures under implementation.

Part IV: Social elements, Participatory Planning and Sustainability Issues

Part IV briefly emphasizes on the need for a participatory and holistic approach for planning soil and water conservation measures. The section outlines the need for participatory planning and beneficiaries involvement in all stages of the planning process, from the appraisal and analysis of constraints and potentials, the identification, selection design, implementation and monitoring and evaluation of suitable and feasible technological packages. For detail information and description of planning procedures, technicians should refer to the Village Level Development Planning Guideline prepared by the project. The planning guideline, in its present or revised (based upon experience) form should be considered as the main reference for participatory and integrated planning for sustainable development of the Dry Zone.

Therefore, within the context of this manual. Part IV, simply outlines the importance of participatory planning, its nature and scope and the main elements of planning which should be considered for preparing flexible, grass-root level oriented and integrated conservation-based development plans.

Part V: Soil and Water Conservation Measures for the Dry Zone

This part represents the core of the manual and includes a comprehensive description of the different measures likely to be of relevance under Myanmar conditions. Many of the measures described in this section have been proven effective within a wide range of conditions in the project areas. Therefore they have a considerable potential for wider application and adoption in several locations of the Dry Zone. Other SWC practices, particularly those related to agronomic measures, agroforestry, silvipasture, woodlot management and rainfall multiplier systems for forage and crop production seem also promising but additional testing, results and experience is required before ascertaining with certainty their relevance under Dry Zone conditions.

Regardless of the results, there is ample scope for additional improvements, refinements, variations and new technologies to be inserted. Soil and water conservation is to be seen as a dynamic process, continuously evolving towards better results and performance based upon land users response and capacity to react, adapt, innovate and bring changes to the proposed technical packages. It is a flexible and challenging process which should be tailored around each and every local condition without prejudice and simplistic views about what is to be done for solving problems related to the land and its users.

Part V is structured as simply as possible. An introductory part explains the nature and scope of soil and water conservation activities in the Dry Zone and elaborate on some of the issues considered essential for their correct selection, design and implementation. For instance the issue of physical measures versus biological ones and the need to integrate both, the issues of sustainability and replicability of SWC measures, the logic of the interventions within defined territorial units and integration requirements. Other important issues are also briefly tackled upon such as the use of incentives for soil and water conservation, the need for consultative negotiations with land users and the importance of flexibility in the choice of SWC measures, the role of traditional knowledge and experience as a source of inspiration for the selection, adaptation or improvement and implementation of suitable techniques for SWC and the need to establish a learning process through field experience and networking.

The rest of Part V include a wide range of SWC measures described for each main land use found in the Dry Zone, namely cultivated, grazing, forest and gully lands. The section also emphasizes that this distinction is mostly artificial since the land is often of multipurpose use and therefore linkages between land uses and activities should always be taken into consideration. Soil and water conservation measures described in the guideline are both physical and biological. For each measure the following information is provided: definition and scope, technical specifications, work norms and inputs, management and integration requirements, limitations, training needs and variations to original design meant to accommodate several land users and landscape conditions requirements.

PART I: PROFILE OF ARID AND SEMI-ARID REGIONS

1. DESERTS, ARID AND SEMI-ARID LANDS

1.1 General

Of the total land area of the world, the desert (hyper arid) zone occupies 4.2%, the arid zone 14.6% and the semi-arid zone 12.2%. It is almost 1/3rd of the total area of the world (see page 5). It has been estimated that drylands alone are inhabited by 1.5 billion people, out of which around 500 million are amongst the world's poorest people, living mostly on marginal areas severely prone to and affected by desertification.

The delimitation between arid and desert areas is determined by the rainfall range. The Northern limit is of about 100-200 mm while the Southern limit (including semi-arid areas) is indicated around 750 mm rainfall. In all instances we have a long dry season (8-9 months), high temperatures (25-30° C or more), high evapotranspiration from the leaf area of vegetation and evaporation from soil surface.

Another definition says that desert starts when we can not observe organized forms of human activities, even those associated with the pastoralists and their herds. However, even this definition is subjected to fluctuations since rainfall is not an uniform variable and varies over time and space.

It is generally accepted that frequent variations of climatic conditions can be indicated as the prominent factor responsible for an increase of arid conditions.

The Myanmar Dry Zone covers 677,000 km^2 (17% of the country). About 11 million people live in the Dry Zone (27% of the country population), with an average population density of 99 persons/km^2 (F.R. Beernaert- 1995). The entire area is considered affected by various levels of soil erosion. In several townships (Kyaukpadaung, Magway, Chaung U, Thung Tha, Nga Htoe Gyi, Ma Hlaing, etc.) land degradation and erosion rates are severe, leading to chronic food insecurity and various degrees of poverty.

In Myanmar, semi-arid areas are recurrently affected by periods of drought. The interval between two droughts varies from one area to another. The level of aridity is also influenced by human activities, which often contributes to aggravate the drought effects on people. The rapid degradation of the Dry Zone is resulting into a progressive and accelerated "desertification" process.

At current rates of population pressure and erosion levels, **drought events normally occurring every 5-10 years may show up at a shorter interval.** There is nowadays ample evidence that the recurrence of droughts in the Dry Zone seems to have considerably increased since the last two-three decades. For instance in Kyaukpadaung township where two years out of three are now affected by low rainfall and prevailing crop failure.

1.2 Climate

1.2.1 Zonation

Arid and semi-arid zones are characterized by an extreme diversity (soils, geomorphology, vegetation, water balance and human activities) that makes classifications and definitions difficult. Several indexes have been developed. The one given below is based on annual rainfall and should be taken as a reference.

Rainfall Index (Le Houérou - 1973)

Climatic zone	Mean Annual Rainfall	Geographical area
Desert zone	below 100 mm	North and South Sahara Middle Ease deserts
Arid zone	100-400 mm	North Africa, Sahelian zone south of the Sahara Mediterranean steppe of North Africa
Semi-arid zone	400-600 mm	Sudano Sahelian zone, India, Myanmar, etc.

In 1979, UNESCO published a new map of the arid zones, based on the ratio P/Etp (P = precipitation; Etp = potential evapotranspiration). As the level of bio-climatic aridity is depending upon the relative importance of water inputs and water outputs, this ratio was found more convenient than the figure P - Etp, which gives the water available but does not reflect the aridity: for example, P - Etp. = 400 either with P 1000 and Etp 600 or with P 600 and Etp 200.

P/Etp expresses well the level of aridity as it gives the same value for all climates in which the percentage of potential losses of water to rainfall is the same. Therefore, a small index means a great aridity.

1.2.2 Rainfall

Higher annual precipitation is required in summer rainfall areas than in cooler rainfall climates to obtain the same amount of water available to the plants.

Rainfall also varies from one year to another in arid zones. **Differences in years are ± 50% of the mean annual rainfall. The variations in monthly rainfall is even greater. These variations are very important for cropping and forestry activities (particularly at the establishment stage).**

Rainfall intensity must be considered: **areas of low annual rainfall may receive heavy individual storms causing flood and severe erosion.** This is an essential parameter for the design of most conservation structures which have to accommodate or divert excess run-off from destructive showers occurring within a very short period of time. Accordingly, **an important parameter to know for the prediction of soil erosion and the design of conservation measures would be the maximum fall within a 30 minutes period** (see part III, page 56).

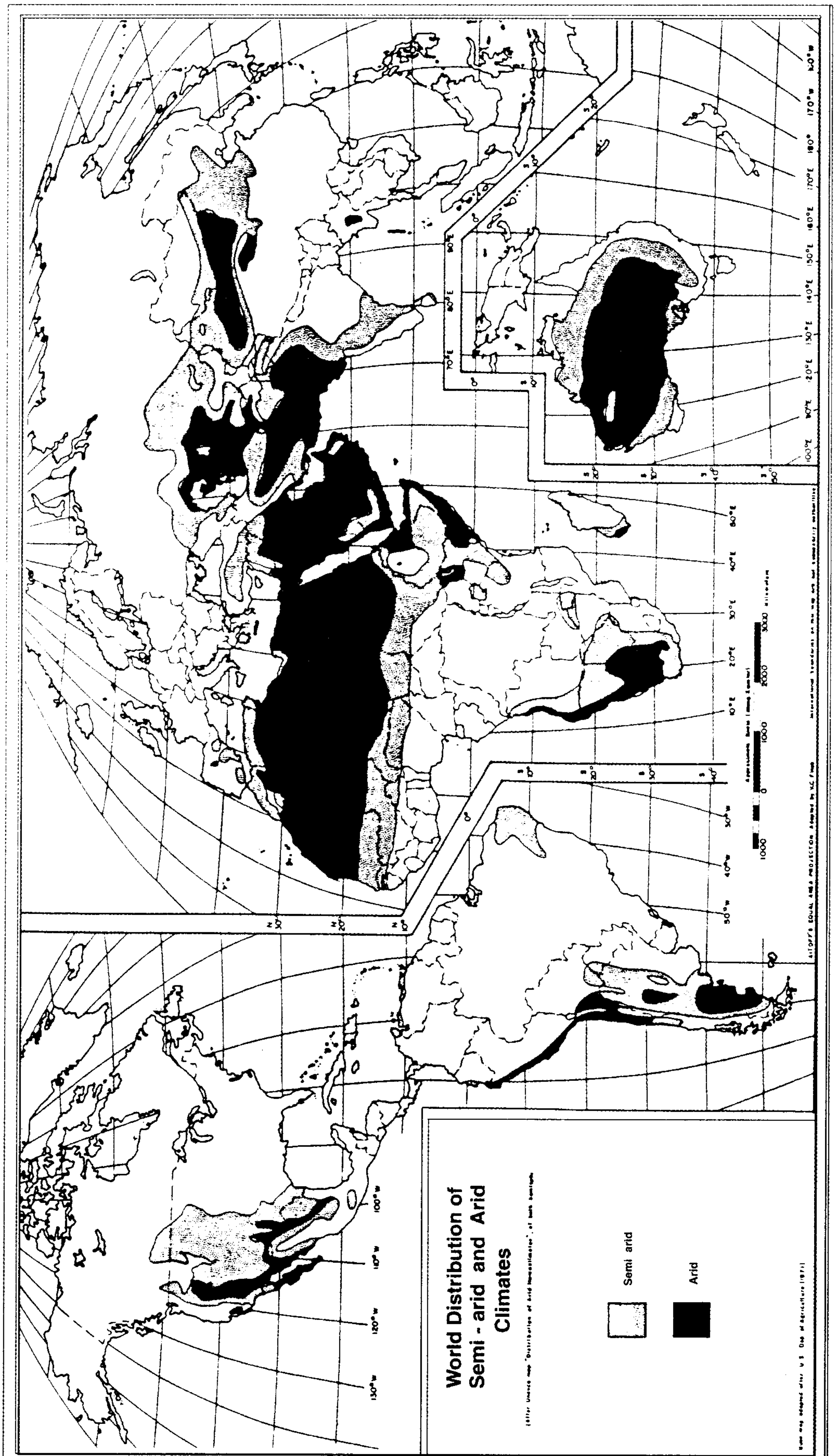


Figure 1 Generalized World Map of arid and semi-arid regions

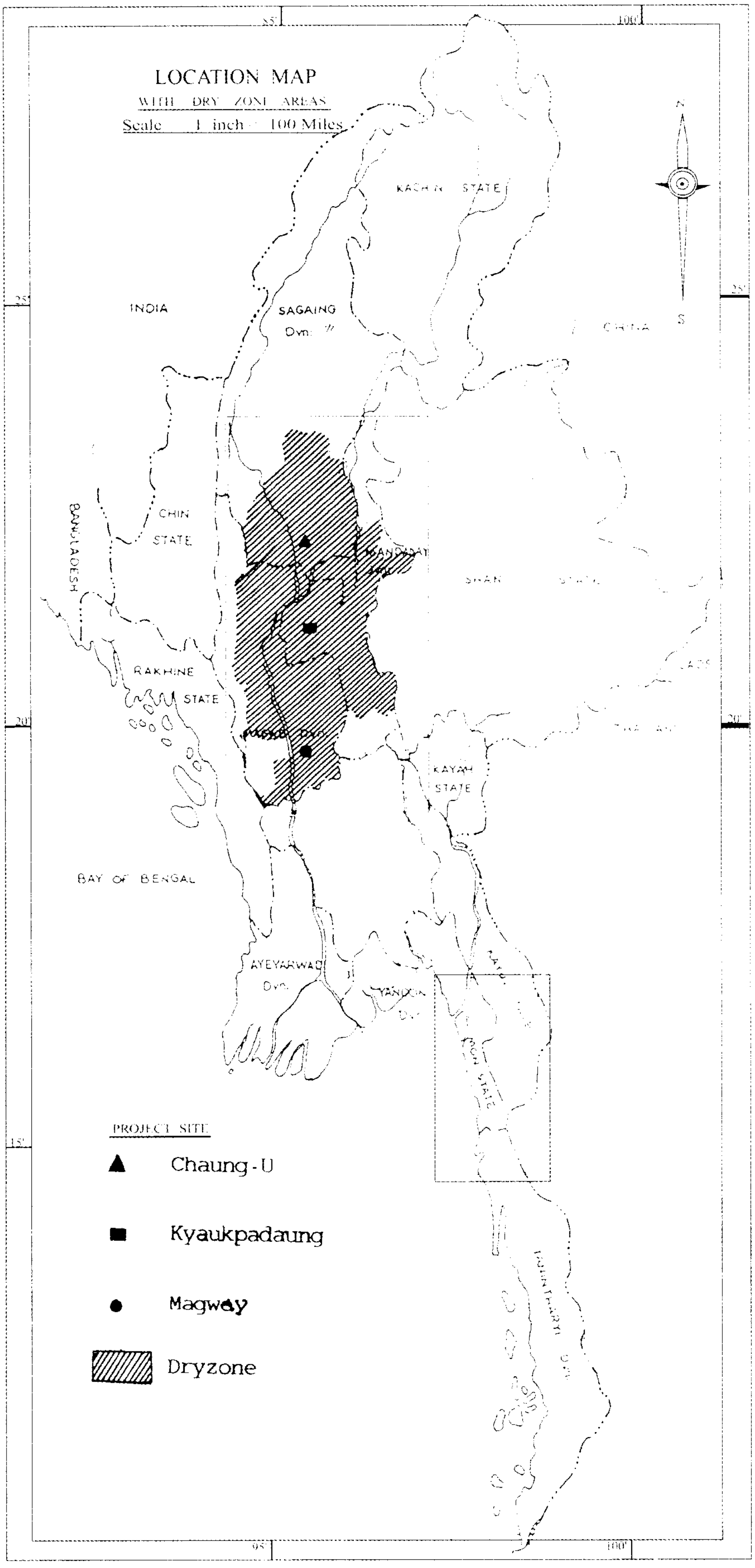
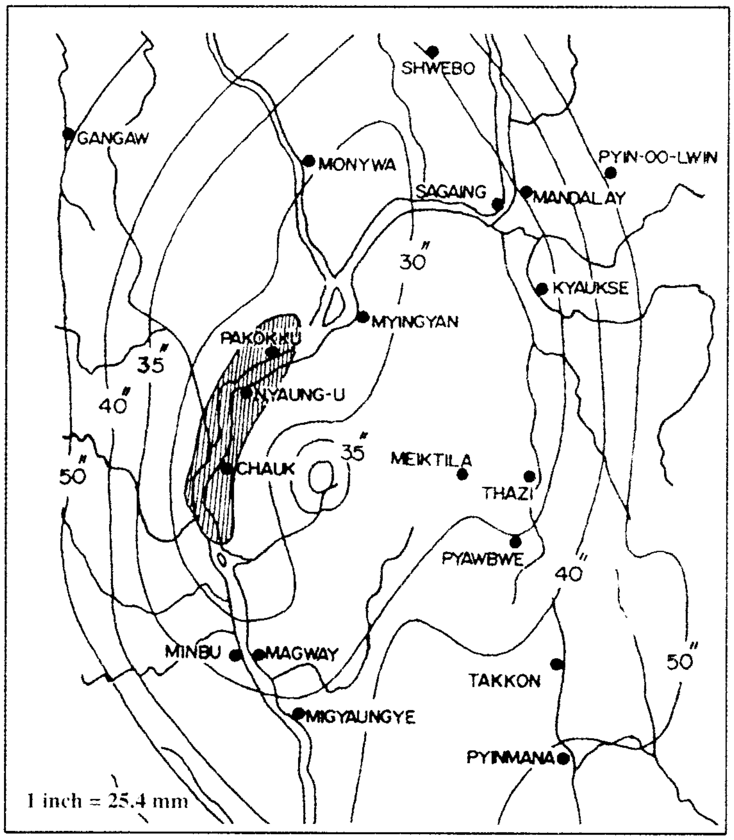
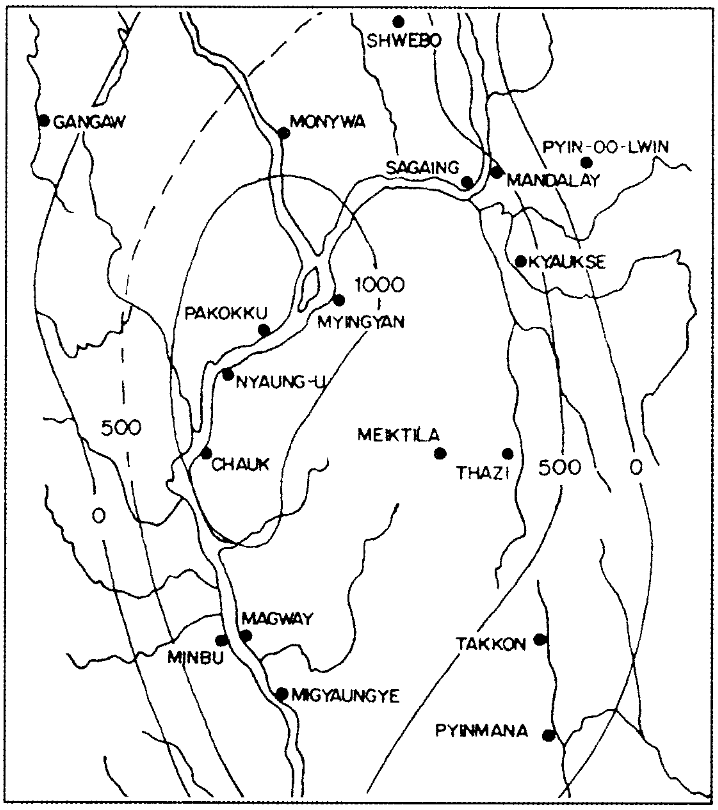


Figure 2 Map of the Myanmar Dry Zone



Mean Annual Rainfall of the Dry Zone



Annual PET minus Rainfall

Figure 3 Mapping aridity in Myanmar Dry Zone (based on rainfall)

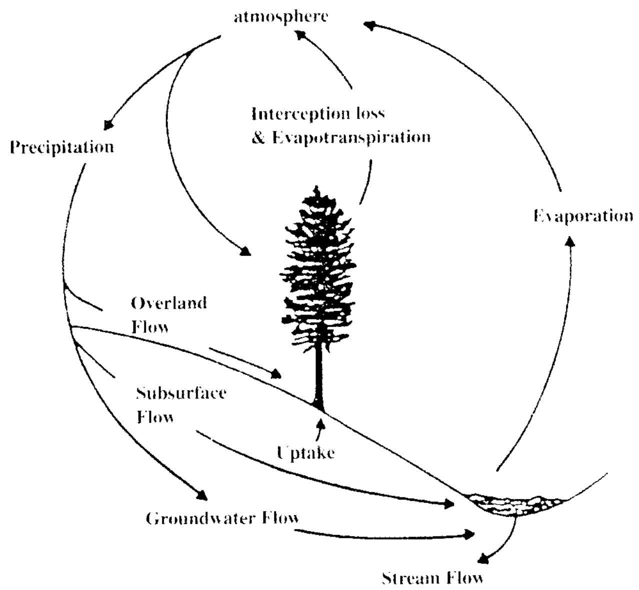


Figure 4 The hydrological cycle

There is an increased variability with increasing dryness: In the semi-arid tropics, at mean annual rainfalls of 200-300 mm, the rainfall in 19 years out of 20 typically ranges from 40 to 200% of the mean, and for annual rainfalls of 100 mm the range widens and is 30 to 350% of the mean (FAO 1981).

In dry zones rainfall is unreliable over space and time: in large watersheds only 20-60% of the area may receive rain.

It is difficult to associate the amount and time of the first rains with the total amount of rainfall in a year. In few countries (Kenya) there are some attempts to categorize the mean annual rainfall based on the timing and amount of the early rains. In this respect there are strategies developed to contrast a negative prediction by changing or diversifying the type of crops.

1.2.3 Temperatures and winds

Temperatures are high during several months of the year, with typical diurnal variations ranging from 10 to 45° C. In many situations, the fluctuations restrict the growth of plant species.

High temperatures at the soil surface results in rapid loss of soil moisture **due to high levels of evaporation and evapotranspiration.**

Arid zones are often windy because of limited or lack of vegetation. **Hot dry winds have three effects:**

- reduce the effectiveness of rainfall **by evaporation from soil surface,**
- increase **evapotranspiration from the leaf area** of crops, increasing the risks of moisture stress,
- surface of **stored waters (ponds, dams etc.) suffer from high evaporation loss.**

1.2.4 Atmospheric humidity

It is generally low in arid zones. Dew is important in several areas since the water condensed on the leaves surface can be utilized through the stomata. The presence of dew or mist in the air will reduce the evapotranspiration and conserve soil moisture.

2. TRENDS AND ORIGIN OF THE PROBLEMS OF DRYLANDS

"Agricultural development naturally takes place first on the best land. Whether at the scale of the individual farm or a whole country, the tendency is to use the best land first" (Hudson, 1997).

When there is a need to increase agricultural production because of internal or external factors (population pressure, animal stocks, decreased amount of agricultural inputs, imports, etc.) it is usually directed to maximizing production in the areas which have the best potential. But as demand increases it is necessary to make increasing use of land which is:

(1) less suitable for agriculture (steep slopes, shallow soils, less fertile areas etc.) or

(2) land located in less favorable climates (erratic rainfall over time and space distribution etc.).

In areas which are naturally receiving less rainfall, this trend leads to the rapid impoverishment and over-exploitation of already scarce land-based resources, the decreasing productivity of agricultural lands and the general degradation of the environment due to accelerated erosion and depletion of soil fertility levels. This is particularly true in semi-arid and arid environments, where the climatic factor plays a determinant role in increasing the vulnerability of such lands to erosion and degradation. Dry zones receive naturally less rainfall and the vegetative cover is by far less important than the one present in other areas receiving higher rainfall. The range of food, fodder and tree crops suitable for arid zones is also limited and production is generally low. Within this context it is understood that food shortages and consequent poverty can be easily triggered by an extensive and irrational utilization of natural resources due to the rapid increasing of human and livestock population. **Once started, erosion and degradation in arid and semi-arid lands continues and expands at a fast pace, beyond the capacity of the land users to control. Ultimately, the level of aridity and recurrence of droughts increases as a result of the degradation process, thus increasing the complexity of the problem and the solutions required to solve it.**

In the Myanmar Dry Zone the process of land degradation started centuries ago, perhaps even at the time of the construction of the thousand temples of Pagan, by using fuelwood to bake the bricks required for their edification. The flourishing of towns and cities in the dry zone, followed by an ever increasing population, brought a growing pressure on the existing fragile environmental conditions of the area. To provide the required amount of agriculture produce, the land has been used extensively and beyond its capacity. Most probably, in the last hundred years, **the degradation process has gradually entered into its accelerated stage, by plunging into the vicious and downward spiral of poverty-land degradation-increasing population trap.** The results are nowadays visible with appalling intensity, i.e. huge gullies dissecting the landscape in all directions, cultivated fields with shallow soils, surface crusts, critical reduction of fresh water supply, salinity and sodicity problems, sedimentation of reservoirs and river beds, food insecurity and migration.

However, "We cannot alter the unreliability of the rainfall, nor the fact that unpredictable rainfall and the occurrence of droughts are inevitable. Neither can centuries of abuse and mismanagement of the land and the people be corrected overnight" (N.Hudson, FAO Bullettin No 58, 1987). Solutions to the problems of the Dry zone of Myanmar should then be sought within this range of limitations which, among several others, are a serious constraint to sustainable development.

3. AWARENESS AND STRATEGIC FOCUS

Awareness creation on the need to address the degradation problem of dry lands has taken place in several parts of the world around two decades ago, after the wave of concern generated by the widespread of droughts in Africa in the early seventies and mid-eighties. In Asia, countries like India and China have since a long time paid attention to their semi-arid and arid zones. In general, following the surge of conferences and workshops in the last ten years on the issues of environmental degradation and desertification, most developing countries have initiated conservation and land rehabilitation programmes with various degrees of success. However, **the pace of land degradation did not seem to have slowed down, let alone stopped, in most of these countries, particularly in the dry zones where the problem need to be addressed systematically and in an integrated manner.**

Within this context, solutions able to tackle the problem of soil erosion and the general degradation of dry lands should be thought carefully, taking into consideration the entire array of components that are making-up the farming system, the thorough analysis of the dynamics of a rapidly changing environment and, as a consequence, of the existing social patterns.

In this regard, decision-makers and experts concerned with agricultural planning and rural development must pay additional attention to the semi-arid and arid regions, both in terms of developing sound policies and strategies for conservation-based development, and providing proper technical assistance and adequate financial support.

4. DROUGHT AND CHANGE

Particularly in the last two decades, arid lands have been associated with droughts and famines. There are different views about the occurrence, causes and effects of droughts. The most important ones are:

(1) **Droughts and related famine are the result of a combination of adverse climatic conditions and human and animal pressure on limited resources.**

(2) **Droughts are basically the result of adverse climatic conditions, human and animal influence marginal compared to the magnitude of the climatic generated effects.**

(3) **Droughts and consequent famine are the direct consequence of the misuse and/ or mismanagement of the land, since the climatic conditions alone would not generate the ecological disasters and famine. This view indicates also that the frequency of a drought increases more or less proportionally to the degree of mis-utilization of the land.**

The definitions given above do not contradict each other as they may seem to be, they simply emphasize different reasons for a drought occurrence based on different situations. Countries differ in terms of agroclimatic conditions even though their rainfall pattern is similar. The same is true for farming systems and social setups.

What is certain is that:

- A drought manifests mainly in dry lands
- A rainfall deficit is always present
- The land is often poorly managed
- Cattle population is often in excess, far beyond the soils carrying capacity
- Population pressure is often high

5. EROSION, LAND DEGRADATION AND DESERTIFICATION IN ARID AND SEMI-ARID AREAS

5.1 Definitions

Very often, when describing the deterioration of soil and environmental conditions, terms such as erosion and degradation are used interchangeably. It is however important that conceptually and practically these terms are clarified and understood for what they exactly mean. First, "land" is a broader concept than "soil", as it encompasses vegetation as well as well as the growth medium itself. Nevertheless, soil erosion is one of the most important components of land degradation. But soil erosion is the process by which soil is being lost by the isolated or combined action of water and wind, in turn influenced by climatic conditions, topography, nature of soils and human activities (including livestock).

Therefore, land degradation can be defined as the progressive reduction of the capacity of the land to sustain life and provide food security.

(a) **Soil degradation:** a reduction in soil fertility caused by erosion (soil removal, loss of nutrients), reduced soil water holding capacity and excessive exploitative use of the land (cultivation of steep slopes, shallow soils, tillage, overgrazing, encroachment of forests, etc.).

(b) **Impoverishment of the vegetative cover:** reduction of the vegetative cover and biomass caused by climatic factors, over utilization of vegetation (cutting of trees, overuse of crop residues for animal feed and fuelwood, overgrazing, burning, etc.), erosion and reduced fertility.

The linkage between the two is obvious: soil degradation is mostly responsible for reduction of vegetative cover, which in turn makes the soil more vulnerable to degradation by erosion. **Similarly, "desertification" is to be understood as the generalized expression of land degradation occurring in arid and semi-arid regions** and not as a "marching" of desert areas.

J.H Durand in his book "A Halt to the Desert", remembers that "Desertification would not occur without droughts". The human factor, though important is placed within its right proportion.

Contrarily, during the UN conference held in Nairobi in 1977 the desertification is defined as follows: *" Desertification is the diminution and destruction of the biological potential of the land, that leads to the appearance of desertic conditions. It is the expression of a generalized degradation of the ecosystems under the combined pressure of adverse and unreliable climatic conditions, and an excessive exploitation/misuse of the land"*. This definition seems to better explain the general degradation trends affecting dry zones.

5.2 Modalities of the Alteration of the Ecosystem

What is happening after the destruction of forests, bush lands and savannas for the purpose of extensive cultivation and/or grazing?

5.2.1 Vegetative cover

Normally around 200 species of trees and shrubs are leaving under tropical forests, less than 25 under savanna and bushlands and from 2 to 4 species of crops in intercropping or other forms on cultivated lands (Figure 5).

The biomass under forest conditions is of about 200-340 Tons/acre, producing a litter of 2-6 Tons/acre. Soils are well protected from sun and rain energy by the layers of vegetation (canopy, understorey, litter). Soils are deep and homogeneous, with rich mesofauna (worms, etc.) which quickly recycles nutrients (turnover). Roots are numerous and manage to penetrate deeply the soil profile, bringing nutrients from deep below up when the topsoil is dry.

Under savanna conditions the biomass drops to 16-60 Tons/acre and the litter from 0 to 2 Tons/acre according to the local practices such as burning and grazing. The biological life of the soil decreases, with termites replacing earthworms in hotter climates. Tunnelling and turning over by termites is less efficient than with earthworms. Soils vary widely and are less homogeneous than under forest. The rooting system is shallower and less widespread. Runoff is therefore much greater, specially after late fires which destroy the vegetative cover before the early rains.

Under cultivated conditions the biomass varies from 0.8 to 8 Tons/acre and the litter (residues) from 0.4 to 2 Tons/acre. Rooting system is shallow and soils may be prone to be affected by high runoff. The biological life of the soil and soil conditions (depth, nutrients, macro and micro-porosity, water holding capacity, structure, etc.) depend very much from the cropping system.

The progressive reduction of the amount of biomass will affect the amount of organic matter present into the soil. Therefore, the rooting system has less penetration capacity, also reduced by cultural practices which generate surface crusting and hard pans under the ploughing levels. The soil coverage is reduced to a period of 4 to 6 months, leaving the soil exposed to high temperatures (mineralization of the organic matter) and erosion risks (formation of crusts and high amount of run-off) by the splashing effect of intensive rainfall events.

5.2.2 Soil

The integration of organic residues into the soil is limited. The soil temperature increases. The organic matter content decreases as well as the microflora and mesofauna activities (reduction of the biological life of the soil). The macroporosity of the soil collapses after some years together with its infiltration capacity. The soil becomes compacted and offers spatial discontinuities: crust layers at the top soil surface and an hard pan under the ploughed layer.

Limited moisture storage capacity which further diminishes the biological activities of the soil and drop of the exchange capacity for nutrients with crops. It increases the possibility of crop moisture stress.

Erosion is rapidly increasing, with high levels **of sheet erosion** that takes away from the soil consistent part of its humus and available nutrients (selective erosion). Shortly, concentration of runoff develops into **rills and gullies** which then dissect the landscape and affect the regime of the main rivers (overflow), causing flooding, sedimentation of reservoirs, salinity, etc. It also **affects the replenishment/recharge of the water tables** and the possibility of utilizing under ground water for irrigation and domestic purposes.

Concluding, in semi-arid and arid zones (< 700 mm rainfall) the reduction of the erosion levels and particularly sheet erosion increases the water stocks available for the crops (ETR), consequently an increased productivity and amount of biomass.

5.3 Understanding the Causes of Land Degradation in Dry Lands

The causes of soil erosion are the most important factors to recognize, not the symptoms. When the symptoms become visible it is often too late or difficult to tackle the underlying causes.

The first question to ask is **why erosion and consequent rapid land degradation occurs in the first place**. The answers to this fundamental question would provide the basis to understand the dynamics of the land degradation process, i.e. the changes occurring to the landscape conditions and to the rural economy, including social implications, and identify the course of action necessary to stop and eventually reverse the negative trend generated by land degradation. Once the process is well understood, decision-makers would be in a position to formulate and implement sound policies, strategies and programmes aimed to address effectively land degradation and poverty related issues. Similarly, technical staff together with farmers would be able identify which technical areas are of critical interest for research, field testing and training, adoption and dissemination, and provide feedback to decision-making.

5.3.1 Why land degradation occurs

Soil erosion, salinity and related problems have faced man ever since he first settled and started to cultivate the land some 7000 years ago. At times the problem has been so extensive that it has contributed to, if not caused, the decline of great civilizations in such places as China, Mesopotamia (middle east), Egypt, North Africa, Ethiopia and Greece (Lowdermilk, 1953). **Under natural and untouched conditions, the rate of soil removal has always been slower-no faster, generally, than the normal rate of soil creation (morphogenesis).** This favorable soil balance was disturbed almost from the moment when man started to till the earth for food. Clearing away the natural vegetation and breaking the ground surface with crude implements, the primitive farmer and his successors unwittingly speeded up the rate of soil removal. But farming went on for centuries before soil erosion became a recognizable human problem. The introduction of the plough, some

2000 years ago (most countries) further contributed to accelerate the soil erosion process, by increasing the area under cultivation and exposing the refined and pulverized top soil to erosion agents.

To overcome such problems and sustain or increase production levels, in several parts of the world, **farmers developed ingenious strategies and techniques for soil and water conservation.** However, the ever increasing population and the need for additional land to fulfill basic needs for food, sheltering and clothing pushed farmers to cultivate steep slopes and marginal areas, encroach natural forest areas and increase the number of livestock.

In dry lands, all forms of agriculture can be described as **water-dependent land use, where water is often identified as the principal limiting factor in biomass production.** The variable hydroclimatic conditions in these regions, combined with naturally low-fertile soils, implies a high degree of environmental vulnerability, seriously complicating human activities in the landscape (Falkenmark et al., 1990). An accelerating population growth (sometimes up to 3% per year), reduces the water and soil resources available for each individual land user, at the same time as demand for food, timber, fuel, fiber and fodder increases dramatically. As a consequence, farmers would tend to shift towards an extensive use of natural resources, i.e. shorten or abandon fallow periods and sound rotations, increase exportation of biomass, etc. Agriculture turns into a purely "nutrient mining" system (Pichot et al, 1981) which ultimately develops into a permanent productivity crisis.

Increasing livestock number beyond reasonable limits and carrying capacity of the land is also a common feature found in most dry zones. The increment of livestock is both a consequence of the land degradation problem and part of its cause. Because of the need for additional arable land, grazing lands were reduced and livestock forced to graze marginal areas, destabilizing the vegetative cover and creating erosion. On the other hand, the general impoverishment of the landscape conditions lead to an increase of the number of animals that could adapt to the changing environmental conditions, for instance sheep and goats, well-known for their contribution to worsen fragile environmental conditions. However, exceptions exists where no significant damage to environmental conditions are provoked by livestock. Therefore, the determination of the influence of livestock in raising levels of land degradation should be area specific and not generalized.

In the Dry Zone, grazing lands are scarce, mostly marginal and degraded lands that provide limited amount of poor quality fodder. Although animals are believed to contribute to the general negative trend of land degradation they may not be amongst the primary causes of it. It appears that there are traditional and cultural control mechanisms over the number of animals per unit of landscape and within the village. However, one may wonder what will be the trend once the increasing number of landless and small subsistence farmers would require, for survival reasons, to increase the number of small livestock and extensively overgraze marginal areas. As a matter of fact, current observations in several locations of the townships assisted by project MYA/99/006 seems to confirm such trend.

Land tenure issues, i.e. ownership and use rights, laws and regulations over communal and private lands, customary rights of land use etc., are important factors that may contribute to land degradation or, as opposed to it, influence the level of care over existing natural resources and mobilize efforts towards land rehabilitation and protection. For instance, several countries loosely controlled communal lands and forest areas have been rapidly

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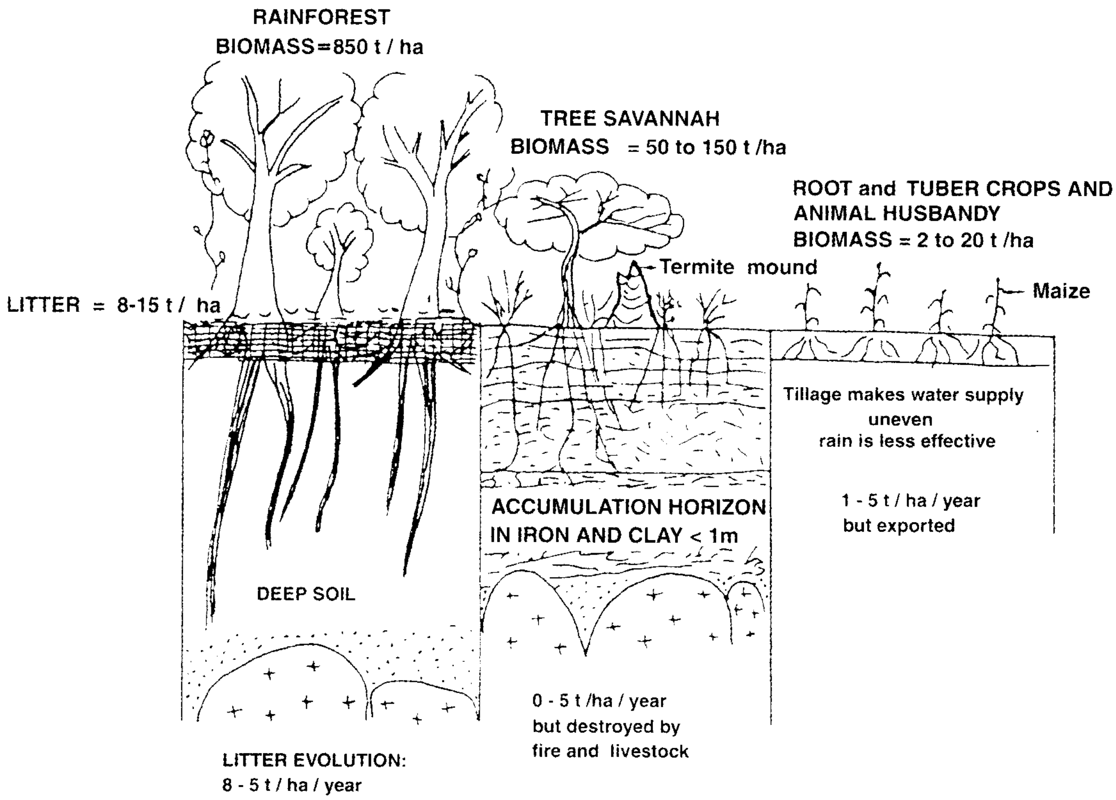
Nature of problams: imbalances in the "managed" environment lead to soil degradation, then erosion speeds up the process



In terms of:

Vegetation..
- Simplification of the ecosystem → decrease in biomass ↘
- Protection of the environment against the energy of sun and rain is less effective ↘

Climate... Rise in temperature → increasing dryness

Soil....
- Reduction of depth of cultivated soil→ Reduction of biological replenishment
  ↘
- ess new litter → { ↘ amount of organic matter in the soil; ↘ biological activity of the soil }
  ↘
- degradation of structure → { slaking crust; ↘ macroporosity; ↘ plough pan } reduction in infiltration
  ↗
- risk of runoff + EROSION + leaching

3 consequences
- ↗ loss of nutrients
- storage capacity (water+ nutrients) → soil depletion
- ↘ water for biomass production

Figure 5 The Variations on the Ecosystem encroached and devastated. In others, the absence of a well defined legislation determining property rights over private holdings discouraged long term investments in land protection and conservation.

Fragmentation and/or frequent re-distributions of landholdings discourage long term investments, make difficult to organize concerted proposals for conservation, increase the complexity of both the planning and implementation processes and increase the costs for land rehabilitation.

In some countries, **civil strife, war, forced villagization, etc., disrupted the socio-economic setup with immediate implications on environmental conditions** (migration waves into fragile environments, concentration of population in areas not suitable for human settlement, etc.).

In semi-arid and arid areas, sudden intense and dramatic droughts triggers the widespread of detrimental coping strategies for survival needs such as the cutting of trees, charcoal making, selling or disappearance of draft animals, reduction or removal of the natural grass vegetative cover, etc. This will accelerate erosion and land degradation once climatic conditions are back to normal.

Use of the land beyond its capacity: because of one or more of the reasons given above land is used beyond its capability. For instance, cultivation extends into marginal areas and steeper slopes, forests or bushlands are cleared for cropping, grazing areas are reduced, fallow periods and rotations shortened or curtailed, biomass is extensively used and not recycled, etc.

Other factors, directly or indirectly responsible for increasing soil erosion, sometimes a consequence and then an accelerating cause of it, are increased population rates, marketing and agriculture produce prices alteration, accessibility, imposed changes of land use, lack of capital, pests outbreaks, etc.

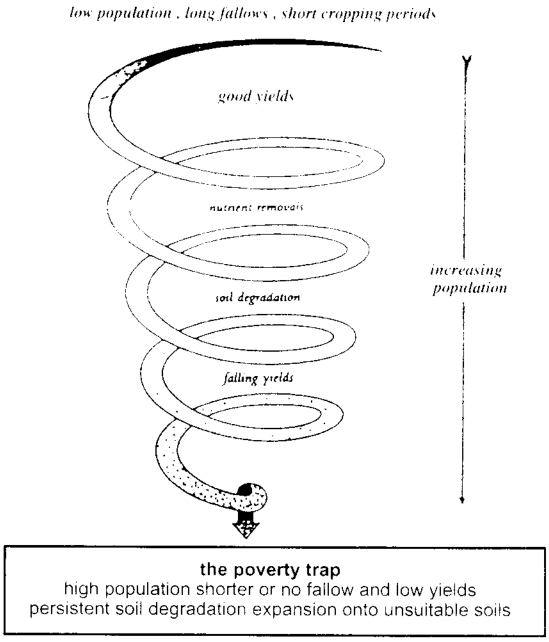
5.3.2 Social implications of land degradation

In the past, centuries ago, people leaving in arid or semi-arid areas had learnt to use the land rather effectively, organizing their activities as per the climatic conditions, using and protecting natural resources in a sound way. If occasionally affected by a drought, farmers and pastoralists could withdraw in an "hinterland" where they survived with their herds until the drought was over.

Since the last several decades the delicate balance between the land and its users became fragile due to the population growth, the introduction of industrial crops and social rearrangements that often clashed with traditional set-ups and sound management of natural resources (land legislation, resettlements, etc.).

Nowadays most of the best land is occupied and the climatic risk push farmers to find additional land by either ploughing up-hill on steeper slopes or expanding their fields into marginal areas. The cultivation of all available land, far from being supported by an intensification of agricultural practices (availability of inputs, utilization of manure and appropriate rotations) is on the contrary an extensive exploitation of the land. To do this, farmers would normally require and need to provide additional labor, particularly during peak periods such as weeding, harvesting, treshing and winnowing. In order to meet the need for additional labor force they naturally tend to make more children. Increased population is also linked with poor family planning, chronic poverty and basic education on prevention methods. However, the trend is usually linked to land degradation and the consequent struggle against survival needs. When the situation becomes too difficult, farmers and pastoralists leaving in dry areas usually react against a drought event by migrating with their herds to better-off areas, seeking for temporary jobs, often in capital cities, where they swell the already overpopulated suburbs. In Myanmar, the excess of labor during slack periods is contributing to high levels of outmigration for extra job opportunities and the need to supplement local meager incomes.

Paradoxically, with the decline of the land-based resources, the desertification process is accelerating the demographic growth and increasing the vicious circle of poverty (see Figures 6 and 7).



Intensified land use in the areas of shifting cultivation leads to shorter rest times for fallow fields and, ultimately, to soil degradation and reduced crop yields. This will inevitably give rise to a non-sustainable system, in capable of supporting a growing community.

Figure 6 The downward spiral to the poverty trap

Emblematic photograph (note the degraded background): the future of this children and their land is at risk.

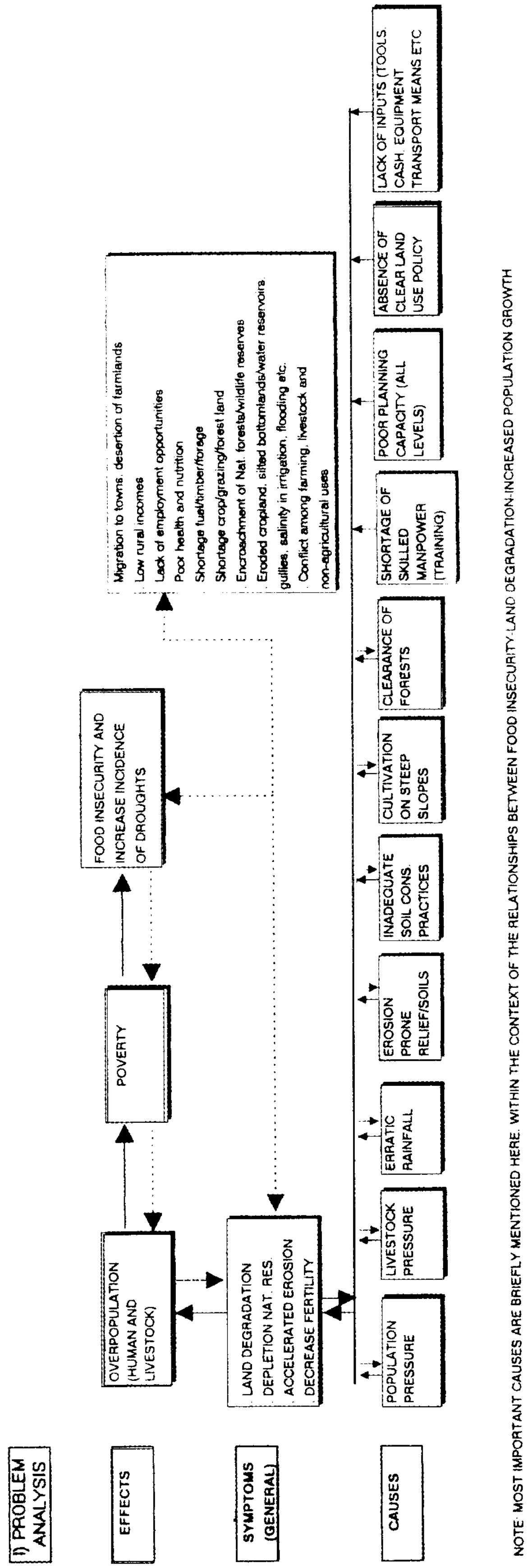


Figure 7 The Land Degradation-Increased Population-Food Insecurity Cycle

6. CONSTRAINTS AFFECTING THE DEVELOPMENT OF RURAL LANDS IN THE DRY ZONE

6.1 Lack of Information

So far, little attention has been paid to the dynamics of erosion/land degradation and desertification processes occurring in the dry areas. In most parts of the world, research and information systems focused on studying and improving the best lands at the expense of the less favored semi-arid and arid areas. On the latter we often lack basic information about climatic conditions, rainfall patterns, drought resistant crops, appropriate conservation measures, vegetation, social and economic conditions etc.

The main fields lacking sufficient information and research on technology are:

6.1.1 Understanding the causes and dynamics of land degradation and desertification

A common mistake is to perceive symptoms as causes. Excess runoff from a gully hit cultivated fields then let us treat the gully; there is a shortage of fuelwood and then let us plant trees; fertility decreases and we should construct bunds. But what made the gully in the first place, why shortage of fuelwood occurred and why fertility decreased steadily are critical questions that should be answered before even thinking what type of interventions to apply. The measures mentioned above should be inserted only after the inner causes of the process have been understood and an integrated and adaptive mode of intervention is initiated. Besides, **land degradation in dry zones is a complex phenomenon that can evolve suddenly into a desertification process once a point of non-return in the exploitation of land resources has been reached and adverse climatic conditions start becoming recurrent and severe, for instance two or three consecutive droughts and consequent crop failures.** As shown in figure 6, the whole process ultimately accelerates, taking the form of a vicious spiral of land degradation-poverty-food insecurity that would become increasingly difficult to reverse.

In Myanmar, considerable efforts should be pursued to enhance the perception and understanding of such negative trends at all levels of the government structure, specially amongst those policy makers and technical personnel called upon to address the issues related to the development of the Dry Zone.

6.1.2 Data on rainfall and rainfall analysis

Regarding rainfall, data from few main stations scattered in the Dry Zone are available. Taking as an example project MYA/99/006 assisted townships, data on daily, monthly and annual precipitation is available from the main stations but data on rainfall intensity are often not analyzed. The analysis of rainfall intensity is very important to determine peak runoff discharges and properly design conservation measures able to accommodate them. However, in the project areas, particularly in Kyaukpadaung, rainfall data are scarce and only two stations are operative (one from MAS in Mt. Popa and one from the Meteorological Dept. in Kyaukpadaung). The station in Mt. Popa collects data from an higher rainfall area, influenced by the mountain range. The Kyaukpadaung station is then the only one recording data that are used for the whole township area. However, a considerable variation of rainfall amounts and intensities is expected to be found in the different villages as per the erratic nature of rainfall. Preliminary data from the rain gauges placed by the project in different villages seems to confirm this pattern. Normally, the wider the variation the higher the indication of accelerated desertification. In Magway and Chaung U, the number of stations is higher but still insufficient for a proper analysis of the variability and distribution of rainfall over time and space.

6.1.3 Data on runoff estimation, soil loss and erosion

There is no research on soil losses and erosion in the whole Dry Zone of Myanmar. Agriculture research stations do not include runoff and soil erosion measurement plots. No erosion and land classification studies and maps defining the capability of the land in terms of sustained production of major kinds of land uses are available. It is then almost impossible to estimate with accuracy peak runoff discharges, data on soil losses and erosion trends if not by using empirical models and approximate estimations.

6.1.4 Lack of technology for soil and water conservation measures and improved agriculture practices

There has been less research on crops suitable for the Dry Zone conditions, soil management practices (tillage, tie-ridging etc.) and soil conservation and water harvesting measures due to the emphasis given to the humid areas and their most cost-effective return. Because of the erratic pattern of rainfall and the wide variation of soils and landscapes, there is a need to develop an equally wide range of measures and crops suitable to dry conditions.

It is clear that under the limitations mentioned above there is a great difficulty to gear research onto a set of technologies adaptable to the semi-arid areas of Myanmar.

6.1.5 Lack of information on socio-economic conditions and farming systems

There is insufficient information on cropping patterns, marketing of agriculture produce, accessibility to inputs, coping strategies, cultural complexities of communal and private ownership, grazing rights, knowledge on settled agriculture and livestock rearing, seasonal transhumance systems, potentials and/or replicability of traditional soil and water and soil management techniques. This information is essential to define major constraints affecting rural communities living in the Dry Zone and find appropriate solutions, particularly in a condition where the **general attitude of the subsistence farmer is to take low risks and where technology development should emphasize on packages able to "improve the odds in the gamble against weather, pests and disease"** (Hudson, 1987).

6.2 Absence of Soil Conservation Policies and Strategies

The absence of conservation policies and strategies is one of the main reasons for most of the problems mentioned above. The general lack of awareness of government institutions on the dynamics and threatening trends of land degradation is a major obstacle to the undertaking of concerted actions able to tackle the problem: **"...Long term degradation issues are not an agenda item until it is possible to show precisely and convincingly how the national economy (and social setup) is affected by the silent crisis of environmental degradation"** (Kebede, Hurni, 1992). So far, the government emphasis on dam construction and irrigation schemes for the Dry Zone as a major means to increase production is not, to say the least, addressing the problem of rapid degradation and food insecurity. Concerning forestry, the activities carried out in the Dry Zone lack substantial strategic focus and planting techniques are often not suitable under semi-arid conditions.

6.3 People's Participation and Selection of Technical Packages

A main component, perhaps the most important one for the success and sustainability of conservation programmes, **is the involvement of the farmers/rural poor in all stages of the planning and implementation processes.** Participation and consultation is essential to share ideas, appraise the farming system, understand constraints and interactions, and develop feasible and acceptable packages for implementation that should meet people's immediate needs while conserving/developing land based resources and protecting the environment. "If conservation programmes are to be effective, every effort must be made to develop practices which not only conserve the soil but also provide short-term, tangible benefits to the farmers" (Kebede, Hurni, 1992).

6.4 Manpower and Skills

Some may argue that the above issues are not new and that different levels of decision-making and institutions dealing with agriculture are aware of the problem. May be so, but the problem of land degradation and desertification need years of field experience and research on the subject in order to be clearly perceived and understood.

In Myanmar, few experts are believed to be sufficiently knowledgeable and experienced to fully comprehend the gravity of the situation affecting the Dry Zone. Besides, this knowledge is not very useful or has limited effect because is not transferred to low level operational staff. Agriculture schools and universities do not emphasize much on soil conservation, particularly for the Dry Zone conditions, and practical experience is virtually non-existent.

Other considerations such as the limited coordination and sectoral attitude of the various ministries and departments dealing with agriculture, forestry and livestock, just naming the most important sectors, is a serious constraint to whatever initiative meant to raise awareness on the problem of land degradation and develop integrated interventions is undertaken.

6.5 Budgets and Inputs

The higher the magnitude of land degradation the more expensive conservation becomes. Then, the budget required for capacity building and resources for planning and implementing conservation measures at a significant scale are beyond the capacity of the government and institutions of most developing countries. Then, external support is often required and should be requested to play a major role in capacity building and testing of improved packages for land rehabilitation and conservation.

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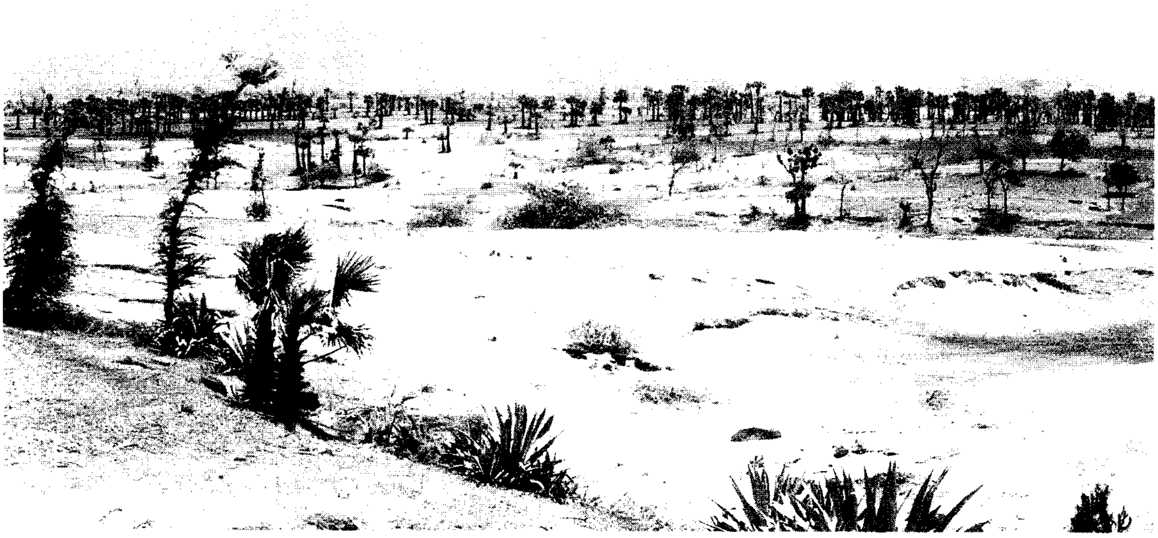
PART II: THE EROSION PROCESS, AGENTS AND EFFECTS



Degraded fields around Mt. Popa

1. INTRODUCTION

The following section would explain and emphasize on the physical processes of soil erosion. As explained in the above chapters, human activities combined with adverse climatic conditions must be recognized as the catalyst to erosion and consequent land degradation.

The word erosion originate from the latin verb "ERODERE" that means "gnawing, incising, biting, etc.". Some authors reached the stage to dramatically compare erosion to the biting at the earth's flesh, until a bleached skeleton of bare rocks remains. However, erosion has always been a natural process since the dawn of time (geological erosion). In millions of years, rain and wind have carved the earth's surface and transported soil particles from place to place. Stream channels and river deltas have been carved out, sedimentary plains formed and landscapes gradually reshaped and transformed (USDA-Soil Conservation Service).

As explained in the above chapters, the erosion rates witnessed today have little in common with the natural phenomenon. To fulfill the demands of a fast growing population, extensive cultivation into marginal areas, overgrazing of pastures and cutting of forests lead to the rapid deterioration of environmental conditions and the appearance of severe forms of soil erosion and high levels of land degradation. Therefore, in addition to fully comprehend the causes leading to severe and accelerated erosion and consequent land degradation, **it is also essential to describe the erosion process in order to identify and design adequate conservation packages aimed to on one hand, protect the soils from further erosion and, on the other hand, improve soil fertility levels for meeting the production requirements of land users.** The following chapters would elaborate on the erosion agents and those factors influencing erosion levels and consequently the type and design of conservation measures needed to be applied.

In terms of erosion, tolerance was defined as soil loss balanced by soil formation through weathering of rocks. Generally the soil regenerates at the rate of 1-12 Tons/hectare/year depending from climate, type of geology and soil depth (Roose - FAO Bull. No. 70). **In semi-arid and arid areas, due to limited moisture and biological life, tolerance to soil loss is much lower (0.2-5 Tons/ha/year)**. However, this assumption is criticized by several authors since the loss of top soil, rich in humus, nutrients and fine particles cannot be compared with the regeneration of an equivalent amount of weathered rocks and sterile materials at the bottom. It is now preferred to define the tolerance to soil loss as the "level of erosion that does not lead to a significant decrease of land productivity". This definition has also problems. First, it is difficult to relate soil loss to the decrease of land productivity. Second, low rates of erosion may not alter the productivity of the land "in situ" but, because of its extent over large areas, can disastrously affect downstream rivers and reservoirs (pollution, siltation, etc.). In general, for practical purposes, the first definition (Tons/ha/year) is commonly used in soil and water conservation.

The main agents for soil erosion are water and wind. Another, less important, but locally of great significance, are the mass movements caused by gravity and influenced by human activities (ploughing, removal of vegetation, etc.)

2. WATER AND EROSION

2.1 Sheet Erosion

Sheet erosion is the initial stage of erosion by rainfall and running water. The term "sheet" is explained by the fact that the energy of rain drops and consequent removal of a thin layer of top soil by water occurs over the whole soil surface. For this reason, sheet erosion is hardly visible from one year to another since a 15-30 Tons/ha/year (6-12 tons/ acre) of soil loss correspond to 1-2 mm of soil depth. Farmers do not notice sheet erosion partly because tillage operations seems to raise (dH 2-10 cm) the ground surface and partly because of the nature of clays that expand when wetted. Besides, effects on crop production are seldom significant in one cropping season and can be easily "hidden" by chemical fertilizer applications. However, **the cumulative effect of sheet erosion over a few dozen years would be responsible for the disappearance of the most fertile (and rich in organic matter) part of the top soil.** Farmers start to perceive that something is wrong when they observe changes in color occurring (bleached, paler and coarser spots) in higher and convex portions of their fields, the increase number of stones and pebbles covering the soil surface, crusting problems affecting infiltration rates and forcing them to increase the number of tillage operations, the reduced efficiency of fertilizers and the general decline of production levels. Other symptoms are micro pedestals or small columns standing towering above the soil level by few mm or cm, covered by a cap of resistant materials such as stones, grains, leaves, etc. The softer soil in between pedestals is been washed away by running water. Micro pedestals are the proof that energy from raindrops attacks the soil surface and that runoff removes the finer soil particles but do not have sufficient energy (at this stage) of incising the base of the small caps.

The agents active in sheet erosion are **the falling raindrops and running water or runoff. Both produce energy able to detach and transport soil particles.**

The detachment of particles is due to the **energy of falling raindrops** (Ellison, 1944). This energy is due to the size (0.25-7mm) of raindrops and their falling velocity. The size and diameter of raindrops influence their terminal velocity. After ten meters of descent, raindrops attain 90% of their final velocity. Generally, studies demonstrated that there is a relationship between the size of raindrops and the rainfall intensity. The higher the intensity the larger the size (although > 75 mm/hr drop size stabilizes) of raindrops and their splashing effect. The wind may increase the energy of raindrops by 20-50% but turbulence reduces their size.

Under some tall trees with sparse canopy and concave shaped leaves (Eucalyptus, etc.), the energy of raindrops may be higher than in the open bare ground because of their concentration on leaves that increases their size. However, under other species or in mixed plantations the lower and dense vegetation that normally grows under those trees would intercept raindrops and neutralize or significantly reduce their velocity.

2.1.1 Splashing effect

Raindrops strike the soil surface and their energy breaks aggregates and clods into smaller aggregates and individual particles (crushing and shearing stress). The impact of raindrops or "splashing effect" throw soil particles in all directions (it remembers the effect of a bomb) and, along slopes, the direction of particles downhill is higher than uphill. Some researchers (Christoi, 1960) demonstrated that particles can reach a height of 50 cm and move as much as 2 meters horizontally during heavy storms. On sloping lands, the proportion of splashed particles that move downhill from the point of raindrop impact is equal to 50% plus the percent of slope of the land (on a 10% slope 60% of the splashing is downhill). Sometimes even more.

Splashing affects the stability of aggregates and the macroporosity of the soil. Small detached particles soon move and seal the pores, reduce infiltration and increase runoff. In dry zones, sedimentation crusts are formed as a result of the splashing effect which reduces infiltration considerably. Other factors contribute to the formation of crusts such as the intrinsic soil factors such as the amount of exchangeable sodium contents. Contents exceeding 15-20% Na^+ facilitate the dispersion of clays and thus, when combined with splash effect, encourage runoff, erosion and crust formation. On the contrary, high organic matter content reduces crust formation by its beneficial influence on the soil structure, specially on the sandy-loamy soils of arid lands. **Surface crusting processes become self-accelerating, promoting more runoff and downhill erosion, and hindering the germination and growth of plants.**

Different types of crusts can be observed (structural crusts, erosion crusts, sedimentation crusts, pavement crusts, etc.) and consist of one or more micro-layers of coarse and plasmic materials. For instance:

- **erosion crusts** caused by splash and runoff which has filled the pores between clods.
- **structural crusts** with coarse sandy microhorizon overlaying a seal made of finer particles.
- **crusts by submerged sedimentation** are formed in depressions or collection points, where larger soil elements sink to the bottom and finer elements stay at the top. When dry they tend to break-up into curled-up plates. This process is inverse to the formation of other crusts which are the result of various forms of removal and deposition (sealing) of finer particles, leaving at the surface coarser materials more or less cemented by finer particles.
- **pavement crusts** consists of a more or less dense surface layer of gravel and small stones incorporated in a structural layer of crusts. Pavement crusts are often observed in eroded regosols .

2.1.2 Runoff effect

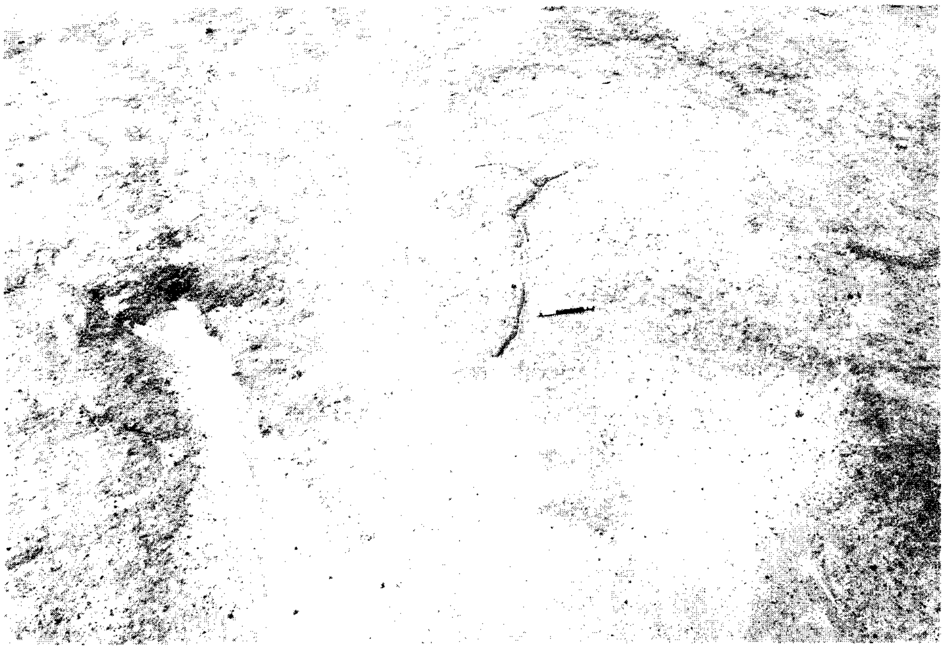
As soon as the soil saturates water start moving downhill and transport particles. **Runoff starts when rainfall intensity exceeds the infiltration rate of the soil.** The depth or thickness of the runoff layer increases with the intensity of the rain as well. Sheet flow has normally a tickness not exceeding 3-4 mm of water. The energy of runoff is related to its velocity. However, it is recognized that the main cause for the erosion process is the splashing effect of raindrops, not the energy of the overflow. Small particles move first (organic matter and fine clays) followed by larger ones (silt, fine sand). The distance traveled by fine materials is greater, leaving behind the coarser ones.

(1) Raindrops impact the soil surface. The water flows around the edges of the stones.

(2) Small rills around the stones are found.

(3) The process of forming rills continue and the "pedestals are formed. The stones present over the soil surface are cropping out.

(4) The stones located at the top of the pedstals collapse and the stones previously within the soil profile are now in the new surface (formation of gravel/stony soils)



Sheet and rill erosion in a cultivated field left fallow: note the deposition of coarse sands in micro-depressions and the appearance of small rills. The rest of soil surface denote the presence of an hard crust.

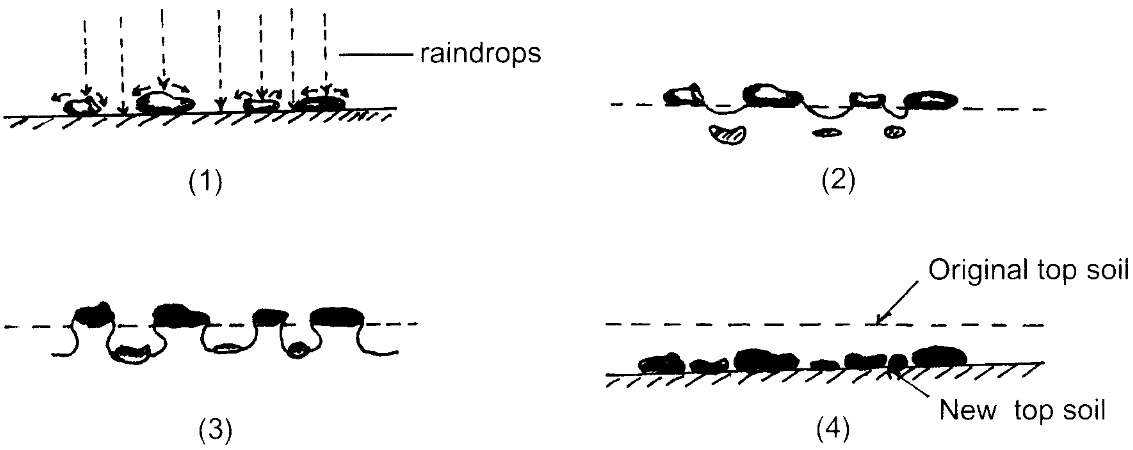


Figure 1 Stages in the formation of pedestals

2.2 Rill and Gully Erosion (linear erosion)

When velocity of runoff exceeds 25cm/second, runoff starts digging into the soil and concentrate its flow in small channels. This is the stage of interrill and rill erosion, leading gradually to gully erosion. The process of **rill erosion occurs when the sheet flow increases its depth and started to organize itself following lines of slope.** Runoff becomes channelized and velocity increases. The energy of water is not dispersed throughout the whole ground surface but concentrates along those channels. The rills are U or V shaped channels, of various depths and widths based upon the soil type and surface conditions.

Micro-pedestals due to sheet erosion: the fine soil has been removed at the base of the small stones acting as a cap

Macropedestals due to sheet and linear erosion in a gully (Kyaukpadaung)

We have small rills of few centimeters depth, rills of 10 to 50 cm depth that still can be canceled out by plowing and gullies that can develop into several meters wide and deep ravines, streams and gorges. Within large gullies we can often distinguish at their bottoms rills or ravines. Some trees, shrubs and grasses may grow in small gullies. In this case they can easily be fixed by the means of vegetative methods or small structures. Large gullies, sometimes of several kilometers long have large stones and boulders at their bottom, witnessing an active and torrential movement of water. They would need systematic checking with large and expensive physical structures.

In nature, we can observe V and U shaped gullies. **V shaped gullies result from homogenous materials, more or less mobile (sandy-clay or clays). The deepening of these gullies occurs during rainstorms of high intensity. U shaped gullies result from heterogeneous materials.** The latter may have hard bottoms and then the canal would be widened laterally during heavy showers. In case of resistant top layers, the gully will deepen until it reaches a temporary or permanent line of ground water. Water will exert a lateral pressure at the foot of the gully side until it collapses (clumping).

Similarly, **streambank erosion**, i.e. widening of the side banks of a river or stream can take place at a disastrous pace during heavy exceptional storms causing very high peak runoff discharges and high overflow velocity.

A very difficult form of erosion difficult to treat is **tunnelling and piping erosion**, sometimes occurring together with gully formation. Piping may happen also on gentle slopes, on soils rich in expandable clays and heterogeneous materials. It is often observed when the content of exchangeable Na^+ is high compared to the content of other exchangeable bases (Ca^{++}, Mg^{++}). Water penetrates through cracks at the beginning of the rainy season and move downwards until reaching the parent material or a hard subsoil layer. Then water makes its way downslope within the lines of minor resistance and dig tunnels that can move rapidly downwards until exiting through the slope, easily forming a gully but may also move upwards, generating a dangerous form of regressive erosion. Tunnelling/piping is a difficult form of erosion to control and only reshaping and filling of cracks with dry soil in order to force water to wet the entire soil surface and not to fall into the cracks is a possible (often expensive) although not always effective measure.

Macro-pedestals are also commonly found in gullies and are the result of both sheet and linear erosion.

2.3 The Empirical Model for the Prediction of Soil Loss: the Universal Soil Loss Equation

Whishmeier and Smith, two researchers from United States developed an equation for determining soil loss by sheet and rill erosion from cultivated fields in order to guide technicians and land users to select adequate soil conservation measures. The equation is a multiplicative function of the following factors:

$$E = R \times K \times SL \times C \times P$$

R = Rainfall erosivity
K = Soil erodibility
SL = Slope factor (gradient and length)
C = Crop management or vegetative cover factor
P = Erosion control practice factor

2.3.1 Rainfall erosivity index (R)

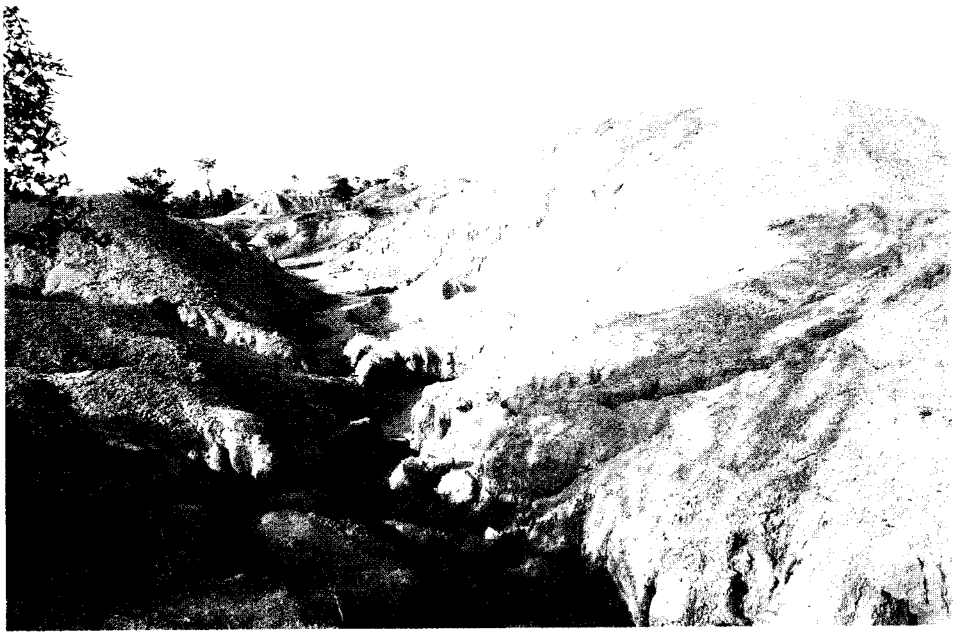
The rainfall erosivity index is equal to E, the kinetic energy of rainfall, multiplied by I30, the maximum rainfall intensity during 30 minutes, expressed in mm or cm/hr. Several tables are developed under USA conditions which may not be applicable for other parts of the world. However, in Western Africa, Roose demonstrated that the average annual R over ten years period is equal to = Yearly mean rainfall x a.

a = 0.5 in most cases
0.3-0.2 in tropical mountains
0.6 near the sea (< 40 km)

Under Maynmar conditions and in absence of research data on the above factors, the simplified Roose equation for determining rainfall erosivity can be considered of practical use though only indicative at this stage. For instance, for a 500 mm (20 inches) annual mean rainfall the Rainfall Erosivity Index would be 500 x 0.5 = 250

Severe rill erosion in a recently sown crop field (Kyaukpadaung)

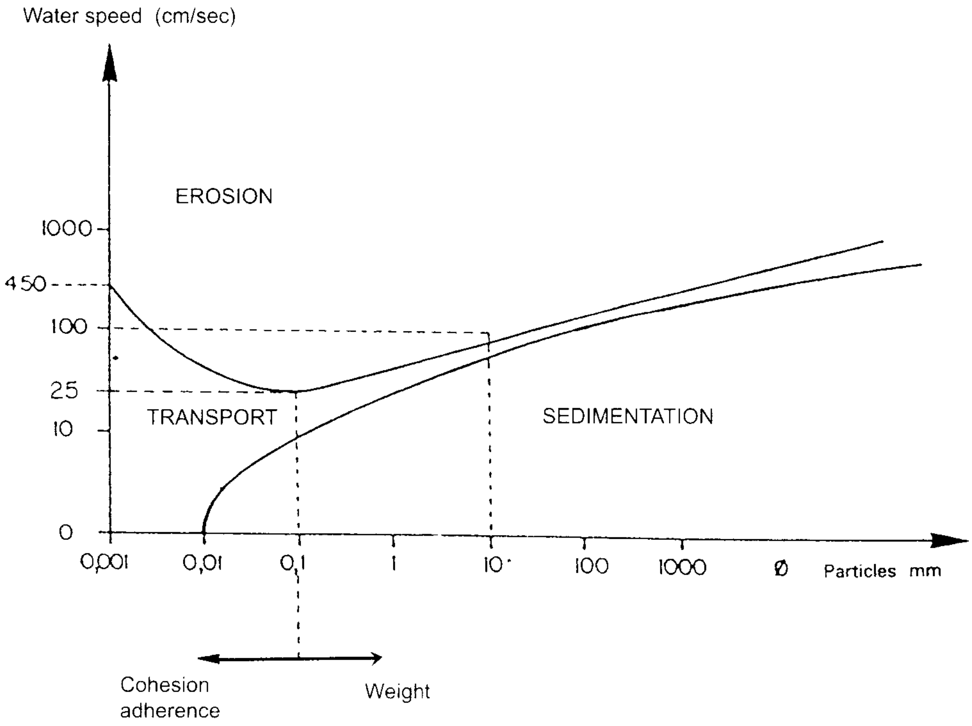
Piping and tunnelling erosion (Li-Pin village - Kyaukpadaung



Examples of gully erosion in the Dry Zone

2.3.2 Soil erodibility factor (K)

This factor is a function of the organic matter content and texture of soils, their structure and permeability. The erodibility of a given soil is influenced by its resistance to two sources of energy: the first is the energy of the splashing effect of rainfall drops, the second is the energy of runoff moving and shearing soil particles through the clods and rills. The Hjulstrom diagram shows that it exists three sectors related to the velocity of running water and the diameter of soil particles. The erosion sector shows that the most fragile particles are the fine sands (0.1 mm). Finer particles have better resistance since they have higher cohesion and larger particles are heavier and more difficult to transport. The presence of stones is also important to reduce soil erodibility, for instance 10% of stones over the soil surface reduces soil erodibility by 15%.



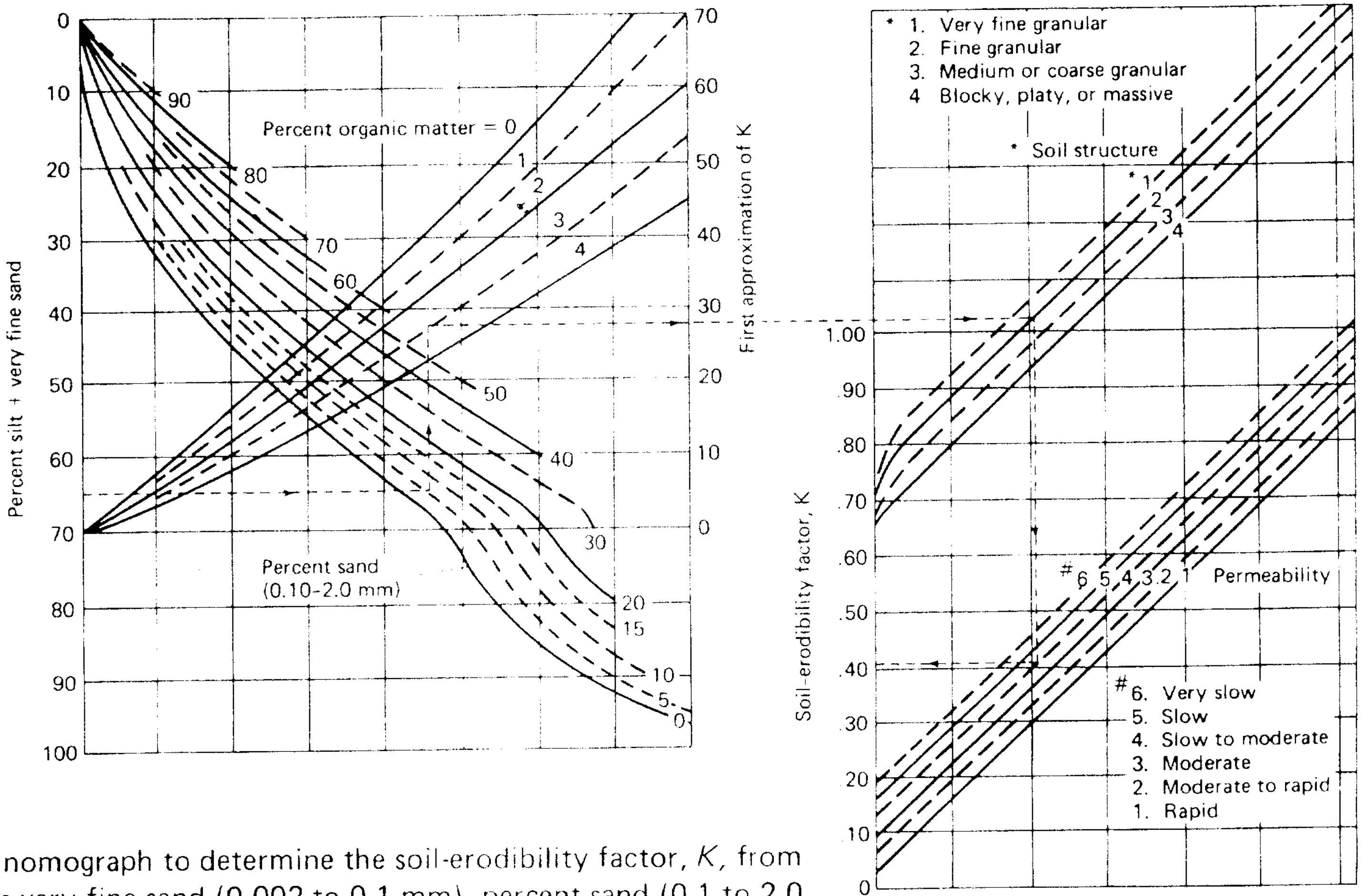
This diagram provides some very important information.

1. The material most easily dislodged by runoff has a texture close to that of fine (100μ) sand. More clayey material is sticker. The coarser material has heavy particles which can only be moved at higher fluid speed. It is interesting to note that for Wischmeier the most erodible soils are those rich in loam and fine sand.
2. As long as the flow is slow (25 cm/sec), it cannot erode. Measures will therefore have to be taken to spread and slow down the flow, in order to prevent linear erosion. This is the basic of the theory of dissipation of runoff energy.
3. Fine clay and loam particles are easily transported, even at low speeds, but in the case of anthing coarser than fine sand, it is a short distance from erosion site to sedimentation site. This explains why ditches to channel runoff water either erode if they are too narrow or steep, or silt up with coarse material which cannot be moved. This is one of the reasons why diversion ditches are unpopular in developing countries, for such ditches and channel terraces have to be regularly cleared and maintained.

Figure 2 The Hjulstrom diagram

In general soil erodibility depends mainly from the organic matter content of the soil (the higher the better), the soil texture, in particular silt plus very fine sands (0.002-0.1mm) and very coarse sands (0.1-2mm), soil structure (porous structure with stable aggregates) and its permeability (deep and well structured soils reduce erodibility).

The K erodibility factor vary from 0.7 on most fragile soils to 0.01 on most stable ones. Under the soil type conditions of the Dry Zone, with soils depleted from organic matter, high percentage of fine sands, tendency to form crusts, shallow depths and poor permeability, the K factor should be chosen around 0.5-0.4.



A nomograph to determine the soil-erodibility factor, *K*, from percent silt plus very fine sand (0.002 to 0.1 mm), percent sand (0.1 to 2.0 mm), percent organic matter, soil structure, and soil permeability. The dotted line shows how the nomograph is used to obtain a *K* value of 0.41 for a soil having 65% silt + very fine sand, 5% sand, 2.8% organic matter, fine granular structure, and slow to moderate permeability. This same sequence of properties must always be used to obtain *K* values from the nomograph. (Modified from Wischmeier and others, 1971.)

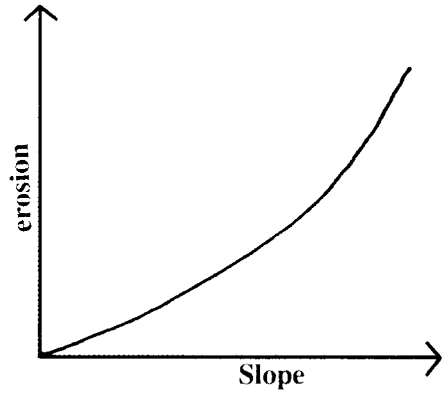
Figure 3 A nomograph to determine the soil erodibility factor K

2.3.3 *The slope or topography factor (SL)*

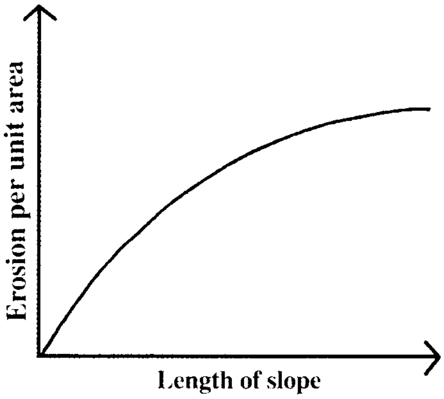
The slope has a considerable influence on the levels of soil erosion. However, even gentle slopes (0.5-3%) can generate a lot of erosion, particularly in dry zones where rainfall intensity can be very high (4 inches/hour and above).

Certainly, slope gradient and length are the most important parameters for estimating this factor.

Slope steepness is the gradient expressed in units of fall per unit of horizontal distance (x by 100 if expressed in %). When slope increases, the kinetic energy of raindrops remain constant but the transport of particles accelerate downhill by the increase of the kinetic energy of runoff. The energy of runoff overcomes the energy of raindrops when the slopes are above 15%. Generally, erosion increases exponentially when there is an increase in the degree of slope

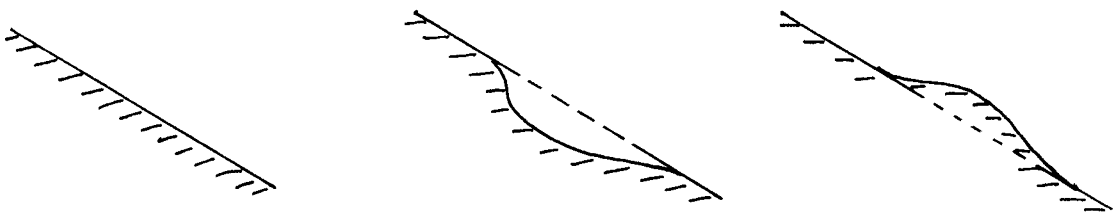


Slope length is the horizontal distance downslope from the point runoff starts to the outlet (waterway, river etc.) or point of sedimentation if slope decreases. The effects of slope length on erosion are evident since the longer the slope the higher runoff accelerates, concentrates and chisels the soil surface. In USA erosion increases exponentially to the length of slope (exponent 0.6). However, data on more aggressive climates are either not available or difficult to estimate. The effect of the length of slope is greatly influenced by the type of vegetation and soil surface conditions. Therefore, in case of sheet erosion, slope length may not be particularly influential but is certainly an important factor contributing to increase rill and gully erosion.



However, the relation between slope length and erosion is complicated by the shape of the slope: convex, concave, complex, regular and irregular. Erosion is higher in convex slopes and than concave ones but the relationship between the shape of the slope and erosion is not well determined.

For practical purposes, the slope length and steepness are combined into a single LS factor. The table and diagram shown below provide indicative LS factors.



Regular slope | Concave slope | Convex slope

Table 1 Values for typographic factor (LS) for various slope length and steepnesses [a]

Slope (%)	Slope length (m)									
	15	25	50	75	100	150	200	250	300	350
0.5	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.14	0.15	0.15
1	0.10	0.12	0.15	0.17	0.18	0.21	0.23	0.24	0.25	0.27
2	0.16	0.19	0.23	0.26	0.29	0.32	0.35	0.37	0.40	0.41
3	0.23	0.27	0.33	0.37	0.41	0.46	0.50	0.54	0.57	0.59
4	0.30	0.37	0.48	0.57	0.64	0.75	0.84	0.92	0.99	1.05
5	0.37	0.48	0.68	0.84	0.96	1.18	1.36	1.52	1.67	1.80
6	0.47	0.60	0.86	1.05	1.21	1.48	1.71	1.91	2.10	2.26
8	0.69	0.89	1.26	1.55	1.79	2.19	2.53	2.83	3.10	3.35
10	0.96	1.24	1.75	2.15	2.48	3.04	3.50	3.92	4.29	4.64
12	1.27	1.64	2.32	2.84	3.28	4.02	4.64	5.18	5.68	6.13
14	1.62	2.09	2.96	3.63	4.19	5.13	5.92	6.62	7.25	7.83
16	2.02	2.60	3.68	4.52	5.21	6.38	7.37	8.24	9.02	9.74
18	2.46	3.17	4.48	5.50	6.34	7.77	8.97	10.03	10.98	11.86
20	2.94	3.79	5.36	6.58	7.58	9.29	10.72	11.99	13.13	14.19

[a] Based on the equations $LS=(length/22.1)^m(0.065+0.045s+0.0065s^2)$, where m=0.2 for s<1%, m=0.3 for s=1% to 3%, m= 0.4 for s= 3.1% to 4.9%, and m=0.5 for s=>5%

Source: Computed from Wischmeire and Smith, 1978

2.3.4 The crop management or vegetative cover factor (C)

The C factor is the ratio between the erosion occurring in a bare soil and the erosion observed in a given production system.

Vegetation intercepts and absorbs the energy of raindrops, reduces runoff and maintains a good porosity of the soil through its rooting system and decay of residues. Amongst all factors, crop management and vegetative cover play the greater role in determining levels of erosion, passing from 1 ton to several hundred tons per ha/year when soil is densely covered with vegetation or bare respectively.

Erosion is always very low when vegetative cover is dense (E = 0.01-1.5 tons/ha/year) and runoff is generally not exceeding 1-10% (KR%) in terms of average rainfall. The type of crops, rotations and management (planting time, tillage operations, etc.) greatly influence the levels of erosion. Normally, **60-80% of annual soil losses occur during plowing**

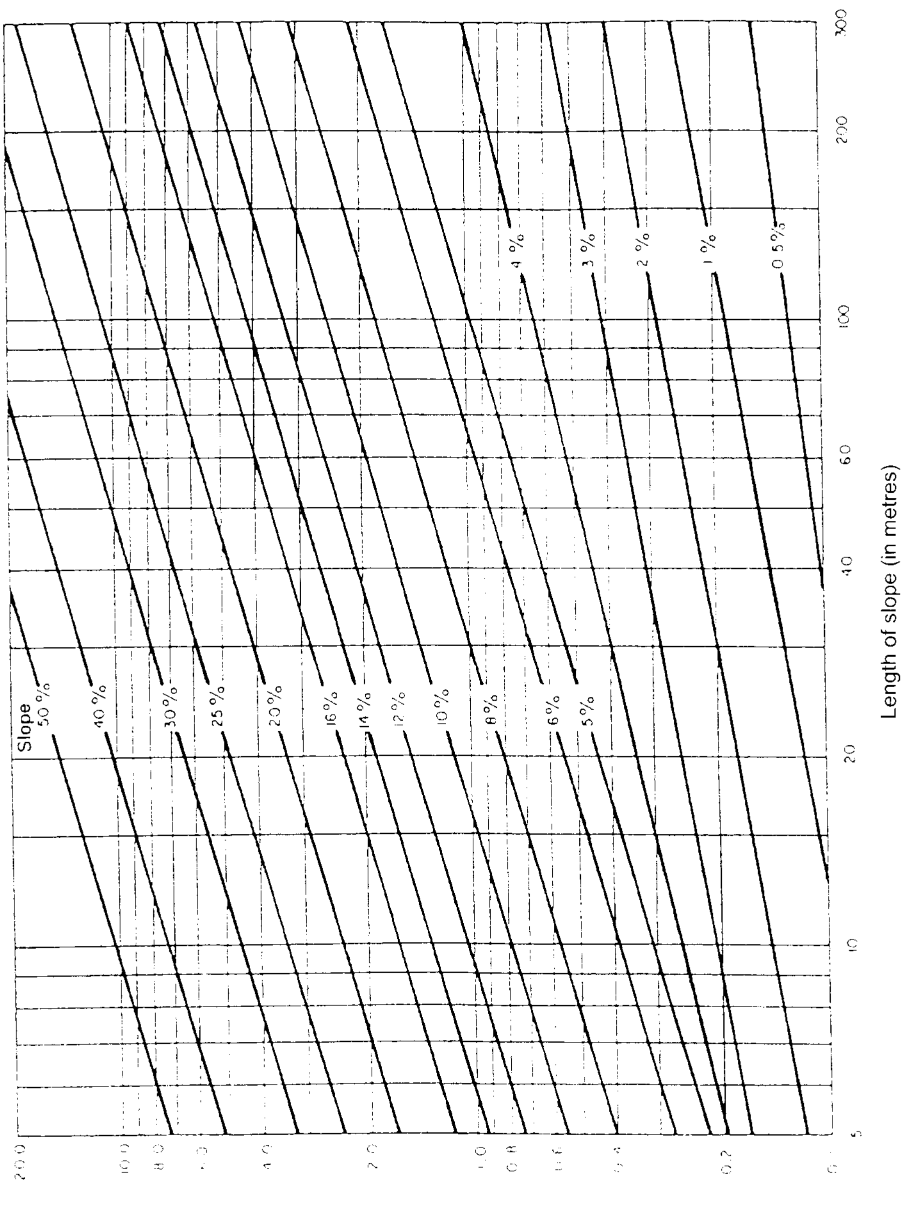


Figure 4 Topographic or slope factor SL (Wishmeier and Smith, 1978)

months and in the first 1-2 months after planting. Some crops such as ground nuts, maize and other cereals poorly cover the soil, and it is only after two months that they reach 80% of surface coverage. Nevertheless, frequent inter row weeding or loosening of crusted surfaces by bullock drawn implements exposes the soil to severe erosion even after crops are fully grown. Better protection is ensured by grass and legume species such as *Stylosanthes, Cynodon and Panicum.* Multi-layered forest also ensure a good protection by intercepting rainfall at different levels and the amount of litter and organic biomass they produce. However, single tree plantations and forests overgrazed underneath may, on the contrary, generate considerable runoff and erosion.

Erosion is not only a function of the vegetative cover but also of the height of the vegetation. For instance, when the vegetative cover is 100% but placed at 4 meters high, the erosion is equivalent to 75% compared to a bare soil field. With the same cover at 2 meters height erosion decreases to 50% and at 50 cm height to 18% of the total under bare soil conditions. In case of a litter of leaves, erosion may decrease up to 3%.

Mulching is also very important to control erosion, even if only part of the soil surface is being covered. For instance, 10, 20 and 50% of an area covered with mulch reduces erosion by 20%, 40% and 70% respectively (compared to the one found under bare soil conditions). The management of crop residues is a critical factor in soil erosion. If crop residues are incorporated within the soil profile (stubble mulching), erosion decreases (50-65%) but not as significantly as if they are left at the soil surface (80-95%).

The **plant architecture** is also important and have an effect on the formation of rills and erosion. There are trees and crops having leaves channeling or conveying water towards their trunk or stems that act as funnels, water concentrating and spreading from their base and/or cutting and deepening the furrows in the direction of the slope. Maize, to some extent, specially in scattered and extensive cultivation patterns, may generate additional erosion by funneling of water. Another architecture is the "umbrella" type, like bananas, that send water outwards. They may also influence the levels of erosion.

Fires can be responsible for very high levels of runoff and erosion, particularly when late dry season fires ravage vast portions of bush or forest lands, burning every twig, canopies, branches and even tall trees. As a result soils are almost bare and with little protection up to one year and often more. Runoff may not only affect those lands but also productive cultivated fields located downstream.

Tillage operations such as deep plowing and chiseling temporarily reduces the runoff rates and increase infiltration but increase the soil erodibility (detachment of particles) and then erosion after few weeks from the time of plowing. However, better rooting and earlier/ faster vegetative cover may compensate for such disadvantages and ultimately erosion is reduced. In dry areas, tie-ridging may be of great advantage. In addition to conserve moisture they check runoff rather effectively. Some of these practices influence also the P factor described below.

Other practices such as the **type of rotation** in place (species, sequence, period, length etc.) with some crops restoring soil fertility, others depleting it and their sequence are also important. Different crops have different rooting systems that can increase infiltration at different depths. Some cover the soil well, others not, some can be intercropped and others produce considerable residues that can be mulched, etc.

Unfortunately, in most dry zones, including Myanmar, the crop management or vegetative factor is high because most rotations are shortened to supply cash or food crops, crop residues are used for several purposes (fuelwood, animal feed, etc.) and tillage operations are superficial and tend to pulverize the soil surface.

The C factor varies from 1 on a bare soil to 0.001 under dense forest, 0.01 on thick grasslands and 1 to 0.8 under extensive cultivation.

The table below provides minimum and maximum average C factors ascertained in West Africa and may be used (cautiously) as a general reference under Myanmar conditions.

F-

Table 2 ***Importance of plant cover and management (C factor) for various crops in West Africa (Roose, FAO Bull. No 70)***

	Annual average C min.	max.
Bare soil		1
Foresr, dense thicket, crop well-mulched		0.001
Savannah and pasture in good condition		0.01
Savannah, or burnt or overgrazed pasture		0.1
Slow-developing or late-planted plant cover, 1st year	0.3	0.8
Fast-developing or early-planted plant cover, 1st year	0.01	0.1
Slow-developing or late-planted plant cover, 2nd year	0.01	0.1
Maize, millet, sorghum (as a function of yields)	0.4	0.9
Intensively cropped upland rice	0.1	0.2
Cotton, second-cycle tobacco	0.5	0.7
Groundnut (in relation to yields and planting date)	0.4	0.8
Creeping cowpea		0.3
Cassava, 1st year, and yam (as a function of planting date)	0.2	0.8
Palm, rubber, coffee, cacao, with cover plants	0.001	0.3
Flat-planted pineapple (as a function of slope), planted early	0.001	0.3
- with burnt-off residue	0.2	0.5
- with dug-in residue	0.2	0.3
- with residue on the surface	0.001	0.01
Pineapple on tied ridges (7% slope), planted late		0.1

2.3.5 The erosion control practices factor (P)

This factor is a ratio between erosion occurring in a field treated with conservation measures and another reference plot without treatment.

Contour cultivation is always effective in reducing soil loss from a particular field, specially during low-to-moderate intensity rainstorms and on gentle slopes (2-8%). Under dry zone conditions and the occurrence of heavy showers, contour cultivation should be combined **with bunding or terracing.** However, although terracing is most effective to reduce soil loss because it reduces the slope length, for this purpose it is not often included in the P factor. Stone lines along the contours (permeable or semi-permeable) and contour ridges, contour hedges and other traditional barriers (trash lines, etc.) should be also evaluated from the point of view of their effectiveness in reducing erosion.

The P factor varies from 1 in case of bare plots without erosion-controlled measure to 0.1 in case of gentle slopes with tie-ridging system along the contours and contour stone lines spaced at regular intervals in the field. Under Maynmar dry zone conditions, a rough assessment of the P factor placed it around 0.5-0.8 in most cases.

2.4 Limitations in Use of USLF

The USLE is applicable for sheet and rill erosion, on gentle and uniform slopes generally not exceeding 10% gradient. It has been tested also on steeper slopes (up to 20%) but does not seem to be applicable on steeper and highly erodible hillsides (>40% slope) where the energy produced by runoff is much higher than the one from rainfall. Another limitation is the fact that the model neglects the interactions between factors, for instance between slopes and vegetative cover, etc.

Besides, this model is only valid to estimate average annual soil loss over a period of 20 years and is not applicable at the scale of a single rainfall event. Although the model is based on the research work carried out in the USA, several countries around the world (Zimbabwe, Taiwan, India, Equador, Ethiopia, Mexico, etc..) have adapted the USLE to their conditions, often with good results. It still remains an empirical method and results from its application should be always considered as indicative. Under arid and semi-arid conditions where lack of sufficient information on rainfall, soils, farming systems and traditional soil and water conservation practices is a common problem and basic research on erosion is limited or absent, the USLE should not be used or used simply as an exercise for providing crude and approximate information about the erosion levels affecting a given area.

However, in spite of the approximate results, **the USLE is useful for the purpose of training field staff to consider the different factors responsible for soil erosion**. During field work and survey of sites for soil and water conservation, all factors of the USLE explained above should be considered regardless of the possibility to estimate the tons of soil loss. For instance, a field technicians will learn that in dry zones rainfall is intense and strong convective rainstorms > 75 mm are not rare, that sandy-loams are more susceptible than others to soil erosion and tend to crust easily, that steep and long slopes need barriers along the contours and that the type of crops and residues management would be very important to reduce soil erosion and restore fertility.

Under Myanmar Dry Zone conditions, most of the land is already under severe erosion and quantifying the damage in tons per ha/year may not be of great relevance at this stage since mistakes in terms of over or under estimations are likely to occur. **Soil loss in terms of tons/ha/year can be also misleading in judging soil erosion and degradation levels**. For example soils which have lost their fertile and erodible top layer and expose only hard sub soil, rock or parent material do not show high soil loss rates since they do not have much soil left to be eroded. In this case current soil loss is low but runoff production is likely to be very high and past erosion was certainly severe. These soils are considered severely degraded in spite of low rates of soil loss. Similarly, hard crusted soils may generate high runoff but low soil loss. In Part 3 of the guideline, a land classification system for use in soil and water conservation would elaborate on the importance of the past erosion factor for the determination of the level of land degradation and suitability of land use.

An exercise for estimating soil loss is proposed below based on field observations and the limited information available to date on rainfall.

The soil loss estimated below is only indicative and should not be used to extrapolate assumptions and conclusions for other areas.

Example:

Area: Kyaukpadaung   Village: Kenbarte
Annual mean Rainfall: 500 mm   Land Use: Cultivated land of 1 ha (2.5 acres)

Soils and topography:

- sandy-clay-loams, medium texture,
- soil depth 50-100 cm, farmer reports shallow and coarser materials at the top of his field.
- slope 5-8%, field 60 meters long,
- sign of rills and plowed depressions,
- no buffer strips of vegetation,
- one boundary line with stones and vegetation acts as a small barrier but does not seem to be effective to stop runoff,
- below the cultivated field gullies are observed.

Type of crop and management based on farm owner reports (or your own observation):

- Sesame as first crop and Sorghum second,
- low yields without fertilizers,
- plowing on the direction of the slope,
- need frequent tillage for breaking crusts and weed,
- low fertility in upper parts of the field,
- no mulching applied to the field. Sesame crop residues used for jaggery making and sorghum stocks for animal feed.

Determine factors of the USLE

R= 500 x 0.5 = 250 based upon the simplified Roose formula

K= 0.5 (assuming fine sands are high and organic matter low based on what the farmer reported on yields and need for fertilizers)

SL=1.5 (see table above based on the slope gradient 8% and length of slope 60m)

C= 0.9 (no mulching, poor cover crops, frequent superficial tillage, plowing along slope, etc.)

P= 0.8 (only one permeable boundary strip at the bottom of the field)

Determine soil loss: E = 250 x 0.5 x 1.5 x 0.9 x 0.9 = 151.8 tons/ha/year equivalent to around 1 cm of soil profile. => Life span of this soil (topsoil removal) = approx. 25-50 years. This life is supposed to be even shorter since erosion accelerates, gullies can develop and fertility becomes so low that cropping is abandoned.

2.5 Soil Loss Estimations for Rill and Gully Erosion

Several attempts have been made by researchers to determine the volume of runoff and soil loss in case of linear erosion. However, prediction of soil loss by gully erosion is difficult and models applied in other countries are not recommended here. Runoff from a sub-catchment area can be easily estimated but soil loss depend on the type of soil materials, the height of water fall at the head of the gully, the gradient of the gully and the surface conditions. When volumes of water flow within the gully are known (estimation of catchment area and runoff analysis) the next step should be the treatment of the gully following the specific technical recommendations used for this purpose (see section on SWC measures for gully control).

3. MASS MOVEMENTS AND MECHANICAL EROSION

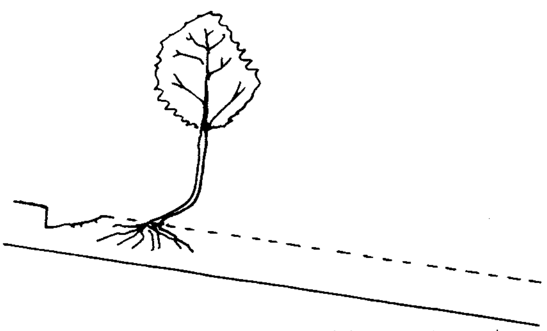
This form of erosion is caused by gravity, pressures from tillage operations and sliding of layers of soil over an harder compacted horizon. The causes of mass movements (slow or rapid) are related to the unbalanced relationships between the mass of the soil, the stock of water it contains, the vegetation on the surface and the friction forces between these materials resting on the weathered rock underneath.

The following forms of dry erosion can be observed:

3.1 Slow Movements (creeping)

Downhill gravitational creeping: it is observed in some steep slopes, with the detachment of the top layers of soil along lines of low resistance where water infiltrates and acts as a lubricant. The trees bend downwards and movements are slow. In some areas animals overgrazing these slopes will add additional pressure and some sort of terraces would be formed.

Dry mechanical erosion: is caused by gravity and the traction exerted by farm operations, plowing in particular. The orientation of tillage operations influence this type of erosion. Movements of soil down the slope are limited during contour plowing whilst plowing downhill drags a slice of soil towards the bottom of the fields (5-10 tons/ha/year) at every pass of implements. To a minor extent this also occurs for harrowing (0,5-1 ton/ha/year). The steeper the slope the faster the movement of soil downhill. After several years, by the combined effect of mechanical and water erosion, the top of the hills appears truncated and bleached, leaving subsoil of poor fertility and shallow depth.



Creep (slow sliding of soil particles on steep slopes)

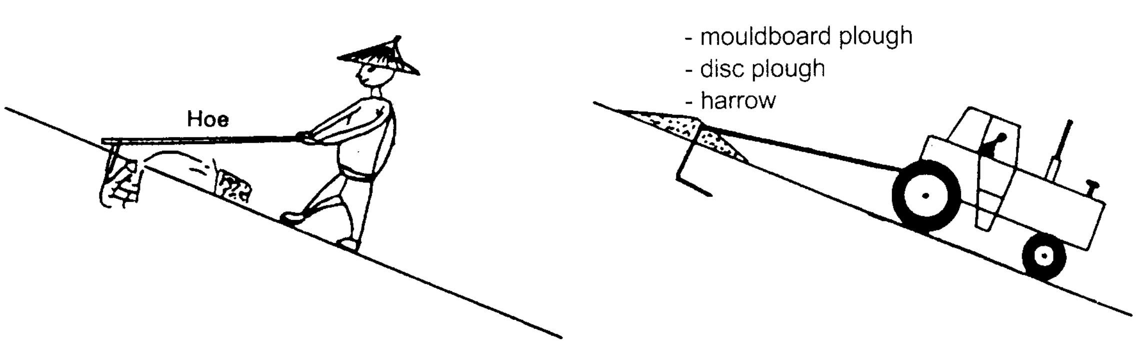


Figure 6 Progressive descent of soil by the tools used for tilling

3.2 Rapid Mass Movements

Sliding of important portions of soils occurs when a layer of soil slides over a compact and harder layer of subsoil or weathered rock underneath (slip plane). It may happen after the alternate contraction and expansion of clays (wetting and drying) and the percolation of water through cracks and lines of minor resistance of heterogeneous materials (tunnelling) and circulation between the lines of internal soil drainage. Water increases the weight of the soil, specially if the soil is rich in clays that expand and swell when saturated. The pressure of the saturated soil and the presence of melted silts and clays that act as lubricants may easily generate landslides and mudflows (point of liquidity).

The removal of vegetation, particularly on steep slopes encourage this process. In some cases, terracing (increase of pressure on the lines of slope) can also trigger mass movements downwards. The form of landslides may be along more or less straight rupture lines across the slopes and rotational or semi-circular (spoon shaped).

Clumping of gully sides and streambanks is also common by the collapse of a slice of the soil profile due to the water pressure percolating through cracks and erosion of the base of the gully sides.

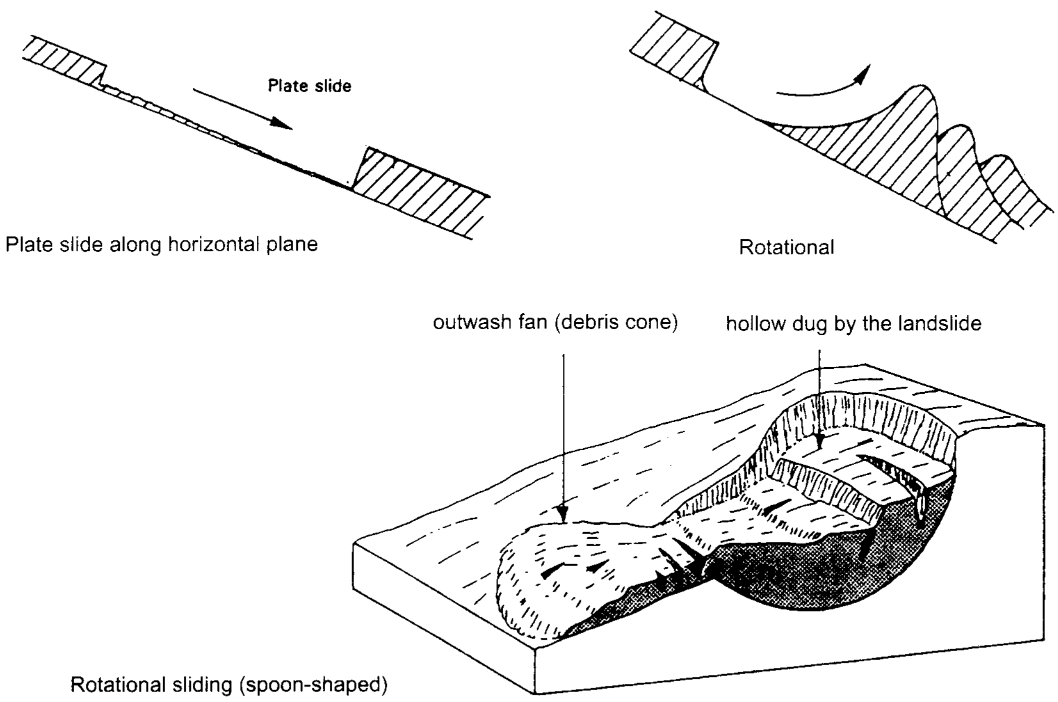


Figure 7 Rapid sliding

Sliding around Mt. Popa

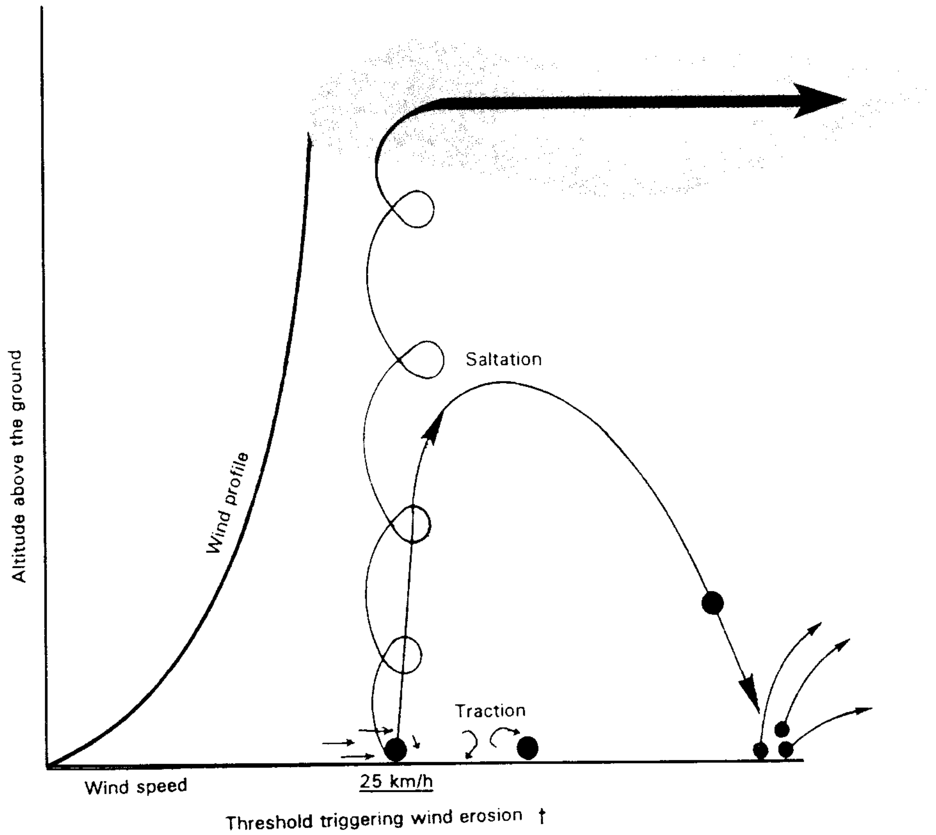


Figure 8 *The three phases of the wind erosion process: suspension, saltation, surface creep (traction)*

4. WIND EROSION

4.1 General

In arid zones, wind erosion is often a serious problem. The destruction of the vegetative cover exposes the soil to the desiccating effects of hot, dry winds, resulting in dust storms, the formation of sand dunes (not in Myanmar), and other forms of severe wind erosion. Winds are not only responsible for the transport of soil particles, but through their desiccating effect, they prevent the growth and development of food crops and livestock production. Similarly to sheet erosion by water, **wind erosion is very selective**. Fine soil particles (clays) and organic matter are detached first and transported long distances, sometimes thousand of kilometers. On irrigated lands, wind, by increasing evaporation, facilitates the upward movement of salts and their subsequent concentration in the rooting zones of agricultural crops. Particles of dust and sand carried by wind can be deposited in communication lines, irrigation canals and drainage ditches, increasing the maintenance costs of road networks and irrigation canals. Wind erosion can be very serious and jeopardize agriculture in arid and semi-arid areas of all continents. In Asia, countries like India, Pakistan, China and Myanmar. are affected by wind erosion.

4.2 Modality of Wind Erosion

Wind erosion moves the soil particles in three ways:

4.2.1 Saltation

Very fine to medium sands (0.05-0.5 mm in diameter) are moved by wind in a series of leaps or jumps, rising into the air and falling again after a short flight. Falling grains knock on others on the ground allowing them to be lifted or bounce back themselves into the air.

4.2.2 Suspension

Clays, silt and organic matter (< 0.05 mm in diameter) are easily raised by the wind force and remain suspended by the air currents for a long time and for long distances. These particles return to earth with rain or when the velocity of the wind is very low.

4.2.3 Surface creep (traction)

Larger particles (> 0.5 - 2 mm) are normally too heavy to be lifted by the wind but can roll by the effect of the turbulence a few meters/hour over the ground surface.

4.3 Effect of Winds

4.3.1 Soil loss, productivity losses and textural changes

Soil loss can be very important. In open large fields with sandy soils left bare for most part of the year, soil loss can be as high as 50-150 tons/ha/year. The selective loss of colloidal clays and organic matter leave behind a coarser texture, and the soil gradually looses its fertility and water retention capacity.

4.3.2 Abrasion

Soil particles transported by strong winds hit hard young vegetation and may drastically reduce yields by their direct damage to the tender tissue of plants. Crops such as sorghum, sunflower, vegetables and cotton can be very sensitive to the abrasive effect of winds (specially from sands).

4.3.3 *Sedimentation*

Deposition of suspended material is disturbing but of no great importance for human activities. On the contrary, saltating soil materials can be deposited in irrigation canals and roads. Crops can be buried by drifting soil, particularly when they are planted in furrows.

4.3.4 *Dessication/damages to crops*

In terms of crop production, hot and dry winds blowing over crops increase evapo-transpiration and may drastically affect yields. The combined effect of high temperatures and hot winds may often kill crops (heat strokes), affect the germination of plants and their reproductive stage.

4.3.5 *Affects water reservoirs*

The effect of dry hot winds on increasing evaporation shortens the life of water reservoirs and may contaminate/pollute them with soil materials.

4.4 Factors Affecting Wind Erosion

Soil texture and structure is very important. Well aggregated clods are not easy to erode. Sandy soils with loose structure and high proportion of fine sands are instead very erodible by wind. Some clay soils are also erodible because they may be weathered to fine particles or pulverized by ploughing (vertisols).

Surface roughness also influence the effect of winds. The presence of barriers such as furrows across dominant winds (below 40 cm height otherwise their top is eroded and erosion accelerates), stones, etc., decreases wind speed.

Vegetation is the most important factor. Denuded soils are the most susceptible to damages by wind erosion. Such damages can be diminished or arrested by the establishment of **windbreaks and shelterbelts.** Moreover, crop residues left with their roots into the soil significantly reduce wind erosion.

Soil moisture conditions are very important against wind erosion since water is the major stabilizing agent through its capillary forces which effectively strengthens the soil particles. Wind erosion stops after a rain. A well structured and cohesive soil (also rich in organic matter) will retain moisture longer and thus become less erodible by winds.

4.5 Prediction of Soil Loss by Wind Erosion

Wind erosion processes are difficult to measure. Unlike water, winds are neither spatially constrained by catchment boundaries nor confined to channels. Instead, wind erosion has the potential to occur anywhere and the sediments can be carried distances ranging from few cm to thousand of kilometers, at a great range of heights, and in any direction. This pose significant problems for measurement. In spite of these constraints, an equation very similar to the USLE has been developed by USA researchers for estimating soil loss by wind. However, the model is applicable under the conditions of the infinitely wide and large American plains (Great plains) and would not be applicable under Myanmar conditions.

This guideline include a wind erosion control measures section (see Part 5, measures for wind erosion control) based on the work carried out in several countries as a response against the detrimental effect of erosion by wind.

5. EROSION EFFECTS

The analysis of the erosion process, by its various agents and forms, showed that arid environments are erosion-prone due to the following reasons:

¥ Rainfall erosivity is high in dry zones (rainstorms of short duration and high intensity),
¥ Soils are often erodible (fragile structure, poor in organic matter, have low infiltration rates, etc.),
¥ Vegetative cover is often insufficient and limited to few months during and shortly after the rainy season,
¥ Winds are strong.

As a consequence, erosion rates can be very high and disastrous (over 100 tons/ha/year) in terms of On-site-effects and Downstream or ecological effects.

On-site effects or effects felt principally at the site at which soil is being degraded, e.g., the shift of land to less productive uses, the direct decrease of the areas under cultivation, direct decrease in yields or production intensities and carrying capacities.

"Downstream" or ecological effects outside the immediate site of soil degradation and generally felt more widely, e.g., sedimentation, deterioration in water flow and drainage regimes, and other changes affecting the stability and fragility of the environment.

Most of the erosion problems occurs in the cropland (65%) and **the rate of erosion accelerates** over time. This is explained as follows:

While the quantities of soil being lost are large, the losses in terms of soil productivity are usually even **greater because erosion generally takes away the most productive parts of the soil.**

Reduced soil productivity means less biomass and less vegetative cover to the soil, less return of organic matter, thus accelerating erosion as well as biological and physical degradation of the soil in a downwards vicious spiral.

If such losses go beyond critical limits, irreversible damage and permanent losses in terms of land productivity can be caused.

Erosion reduces the **water-holding capacity** of the soil both by reducing its depth and by changing the soil water holding characteristics (removal of the more permeable top-soil rich in fine soil particles and organic matter) ===> crops became sensitive to water shortages particularly at flowering/filling time.

The above means that in lower rainfall areas erosion reduces average annual crop yields by:

⇨ reduced average yields per crop season,

⇨ increased frequency of crop failure,

⇨ reduced crop seasons (cropping intensity) per year,

› Degradation gradually makes the land more susceptible to the effects of drought and flooding.

Soil degradation damages water and drainage regimes ==> reduce rainfall infiltration ==> increases run-off ==> flooding and sedimentation ==> pollution of streams ==> siltation of dams, channels ==> rapidly reduces irrigation capacity ==> catchment storage reduced ==> springs dry ==> increasing of walking distances to collect water ==>>>> multiplier effect on the national economy.

6. EMPIRICAL ASSESSMENT OF SOIL EROSION IN THE DRY ZONE

As discussed earlier, the USLE model may not be easy to apply under Myanmar Dry Zone conditions. However, the effort should be made for the simple reason that the exercise in itself provides useful information about agroclimatic, soil and landscape characteristics conditions. It provides guidance on what are the main constraints affecting production levels and environmental conditions and suggests the direction to follow to solve problems.

In several countries, soil erosion has become a national concern and considerable efforts have been put into research and soil conservation programmes. Research stations are established with the purpose of scientifically study erosion rates under different land use and soil types, providing useful data on both causes and extent of erosion levels. This information allow field technicians to guide their work in selecting appropriate packages for soil and water conservation.

Research stations typically include erosion measurement plots, with or without conservation structures or vegetative barriers, on bare or cultivated/vegetated soils, different slope ranges and length. The number of plots and repetitions should be sufficient to provide representative data and allow proper statistical extrapolation. A proper set of meteorological instruments is always associated with the research station to measure rainfall erosivity. At the end of the erosion plots, runoff collection devices are placed to measure amounts of overflow and measure soil loss. They are iron cylinders, troughs and other kind of recipients. After every shower, containers are replaced and their content weighted and left to dry in order to measure soil loss. Advanced research may also simulate rainfall by the means of rainfall simulators and thus speed up the process of gathering and analysis of data. However, those instruments are sophisticated and expensive and unlikely to be widely used under developing countries conditions.

Results from research stations are important but are not always representative for a large area. In some countries several criticisms have been made in the past because data from few stations were taken as a reference to design conservation measures for the whole country, with the obvious errors in extrapolation and design of conservation packages, and thus responsible for the poor performance during implementation. Data from research stations are useful but they should be always confronted with site-specific conditions and never generalized.

In absence of research facilities empirical field assessments of erosion levels and soil loss can take place using erosion damage assessment field surveys and empirical measurements of soil loss by the means of caps, graduated sticks planted at regular intervals in the fields, soil deposition along bunds and by farmers perceptions on past erosion, soil conditions and productivity levels.

A field technician may use caps to determine sheet erosion and graduated pegs for sheet and rill erosion. Attention should be paid at properly positioning the devices in the field (top, middle and bottom) and repeat the operation for different types of soils, slopes and production systems. The erosion assessment should include plots with and without conservation measures and possibly one reference plot without vegetation.

In addition to the rough field measurements (every mm of soil loss corresponds to 12-15 t/ha/year), interviews, discussions and field walks with farmers are very important to determine the severity of soil erosion and its effects on production levels.

For instance, cultivated fields with bleached spots at the top, convex shape, sandy-loamy texture, in moderate slope (8-15%), without conservation devices and plowed along the slope, will be certainly be subjected to high erosion rates, likely above 100 tons/ha/year. Steep slopes left bare after recurrent bushfires, overgrazed and deforested will produce high runoff which is likely to deepen and widen existing rills and gullies or generate new ones.

Moreover, farmers (specially the old ones) may recall and describe the conditions of their fields in the same way they can tell about their sons and daughters. They may remember the fertility levels (crops that did not need fertilizers in the past but nowadays cannot grow without them) existing decades ago, the decrease of productivity of their fields in relation to rainfall amounts, describe the evolution of rills and gullies if any, report on the evolution of crop rotations and reasons for change, sense the worsening of climatic conditions, relate the depletion of woody biomass to the levels of erosion and increase of runoff, and discuss an infinite number of other matters that would easily guide field staff in understanding and assessing the severity and extent of erosion trends and their interrelated causes.

The coming sections of the guideline would emphasize on the need of involving land users in every step of the conservation-based development process, from the problem identification stage and links with soil erosion and land degradation, to the planning and implementation of soil and water conservation measures. Both technical (Part III) and social factors (Part IV) will have to be taken into consideration and flexibility would be required to adapt our limited technical knowledge to the myriad of bio-physical and socio-economic conditions existing in the field.

B

EXAMPLE OF AN EROSION DAMAGE ASSESSMENT FORM

Division:__________ Township:__________ Village:__________ Name of surveyor:__________

DATE	EROSION FORMS											MORPHOLOGY				VEGETATION				SOIL	GENERAL REMARKS
	SHEET (bleached SPOTS (% AREA) (1)	SHEET (micro-pedestals) (2)	SHEET (Crusts) (3)	No OF RILLS	LENGTH (rills)	DEPTH (rills)	WIDTH (rills)	GULLIES No	DEPTH (gullies)	WIDTH (gullies)	LENGTH (gullies)	SLOPE (%)	SLOPE (length - mtr.)	SHAPE (slope)	OTHER REMARKS	TYPE (NATURAL)	COVER (%) (3)	TYPE (CROP/FALLOW)	COVER (%) (3)		

SHAPE ▲	OTHER REMARKS ▲	COVER (%) ▲	COVER (%) ▲	SOIL ▲	GENERAL REMARKS ▲
CX convex	filled bunds broken	0-20% very poor	0-20% very poor	color/Ph	e.g. maintenance done
CV concave	bunds (why) foot path	20-40% poor	20-40% poor	depth	on physical structures
Li linear	interflow tillage	40-60% moderate	40-60% moderate	drainage	yes
Dp depression	water from outside upslope,	60-80% dense	60-80% dense	texture	no
	design errors, etc.	80-100% very dense	80-100% very dense	salinity	why not
		mulching yes no	mulching yes	sodicity	

AGROCLIMATIC ZONE:

RAINFALL: PATTERN

1st Monsoon

2nd Monsoon

TEMP:

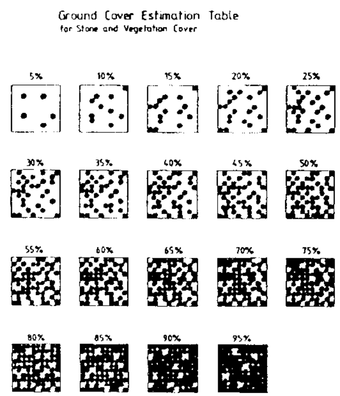
INTENSITY (per/hr)

(1) Enter (o) None, (x) Few, (xx) common, (xxx) very common, (T) almost the whole area

(2) Enter (o) None, (x) Few, (xx) common, (xxx) very common, (T) almost the whole area

(3) Enter (o) None, (x) Few, (xx) common, (xxx) very common, (T) almost the whole area

GROUND COVER ESTIMATION TABLE (for Stone and Vegetation Cover)



Example of an erosion damage assessment form

PART III: TECHNICAL ELEMENTS EFFECTING THE DESIGN AND IMPLEMENTATION OF SOIL AND WATER CONSERVATION MEASURES

1. INTRODUCTION

The following sections are a brief description of some **key technical elements to be taken into consideration prior to the identification, selection, design and implementation of soil and water conservation measures.** Some of these elements are integral part of the planning process (technical surveys) but are described here in greater detail for practical reasons. However, for reasons related to the lack of sufficient and accurate information on the type of crops, rainfall patterns and soil and landscape conditions, most of the surveys and data required to properly design soil and water conservation measures would need to be supplemented with empirical estimations, common sense, farmers suggestions, field trials and lessons learned. Soil and water conservation is a gradual process and should be build-up based upon experience. Ready made solutions do not exist.

The five main technical elements that need to be ascertained with accuracy are the **(i) the behavior of rainfall, (ii) estimation of runoff, (iii) soils and landscape conditions, (iv) the land use and land capability, (v) the type of soil and water conservation strategy to adopt in view of the crop water requirements.**

The following sections are just indicative and are not exactly procedural. They are meant to help field technicians in designing appropriate soil and water conservation measures. It does not mean that you should always undertake a detailed rainfall analysis or a land classification survey whenever you are faced with the need of addressing soil erosion problems. But it is important to develop a clear perception about the erosivity of rainfall by estimating peak rainfall intensities and runoff rates, and assessing soil & landscape conditions conducive to generate high erosion rates.

In case of lack of data and/or access to information, the empirical estimations should be always on the safe side , meaning not underestimate the probability of rainstorms of high intensity and peak runoff discharges (4-6 inches/hr).

Crop water requirements are important to design water harvesting measures meant to increase water into the cropped area by using catchments or impluviums. Here again data may be scarce and/or not at hand. By asking questions to land users you may find the answers on which run-off/run-on rate to apply but not before having yourself estimated the catchment areas and assessed the soil/topographic conditions.

Concluding, the following are basic tools for understanding the bio-physical conditions of your working area that should be used or adapted based upon local conditions, skills and type of interventions.

2. RAINFALL AND RUNOFF ANALYSIS

2.1 General

A detailed method for rainfall analysis is given as a separate guideline. It is extracted from the Lecture Notes provided during the Water Harvesting Training conducted in Myanmar - Maylaing, in December 1997 (Siegert, FAO). Instead, the following paragraphs would summarize the characteristics of rainfall in arid and semi-arid areas and provide empirical methods for runoff analysis, bearing in mind the limited information available in the Dry Zone on amounts, intensity and frequency of rainfall.

2.2 Description of Rainfall - Runoff Relationships

Rainfall and runoff are the two vital aspects of the hydrological cycle that are of interest in the control of soil erosion and discharge of excess rainwater.

Part of the rainfall that reaches the ground soaks into the soil. This process is called infiltration. If the rainfall is greater than the infiltration capacity of the soil it starts to move downstream. This is called runoff.

2.2.1 Defining runoff

Runoff is that part of the rainfall which does not infiltrate into the ground but makes its way to streams, rivers, lakes and oceans.

Runoff is affected by various factors such as rainfall characteristics, soil parameters (texture, depth, structure, permeability and soil temperature), surface cover and land management practices.

2.2.2 Rainfall amount and runoff

A high amount of rainfall produces more runoff than a low amount of rainfall. During high rains the infiltration rate of the rain decreases because the soil intake capacity decreases. Intake capacity of soils decreases because all the pore space is filled up with water.

2.2.3 Amount, intensity, duration, frequency and distribution of rainfall

The amount of rain collected by a rain gauge in a day is the *daily rainfall* and in one year the *annual rainfall*. The *average annual rainfall* is the average estimated over a long period of time (over a decade, better two) at a given station.

Other rainfall characteristics which influence runoff are the intensity, duration, distribution and frequency of rainfall.

(i) ***Rainfall intensity:*** the quantity of rain falling in a given period of time (mm/hr, cm/hr or inches/hour). High intense rains cause more runoff than less intense rains.

How is the intensity of rainfall measured? There are two methods for determining the intensity of rainfall. These are:

- from automatic rainfall recording rain gauge.
- by measuring the amount of rainfall and recording the time taken.

$$\text{Intensity} = \frac{\text{Rainfall amount}}{\text{Time taken}}$$

Rainfall is measured normally in millimeters, time is measured in hours. Therefore, intensity is measured in millimeters/hour.

(ii) ***Rainfall Duration:*** the period of time during which rain falls (hours, minutes, days). A long duration but of low intensity rainfall causes less erosion compared to a short duration of high intensity rainfall.

(iii) ***Frequency:*** the expectation that a given depth or amount of rainfall will occur in a given time (once every year, every three years, etc.). A rainfall of high frequency causes more erosion.

F-

(iv) ***Magnitude:*** amount of rain falling at a point in a day, month, year, etc.

(v) ***Distribution:*** the nature of the convective, high-intensity, short-duration type of rainfall events, typical of dry zones, influence its distribution over time and space. There is an increasing variability with increasing dryness. The general unreliability of rainfall from year to year is compounded by the variations from place to place and from storm to storm. An example of a traditional way to describe the erratic nature of rainfall by farmers living in the Sahelian arid areas is: ...rains may wet the left horn of my cow and leave dry the right one .

2.2.4 Soil parameters and runoff

- Soils with fine texture, e.g. clay soils yield more runoff compared to coarse grained texture such as sandy soils
- Fertile soils have good structure and produce less erosion
- Soils that have low fertility produce more erosion
- When the temperature of the soil is high, runoff yield decreases
- Deep soils produce less runoff than shallow soils

Techniques for identifying the textural classes of soils is given in the following section on Land Classification (page 77)

2.2.5 Vegetation and runoff

- A well vegetated land produces less erosion
- Bare land yields high erosion
- Land with good grass cover produces less erosion

2.2.6 Land management and runoff

- Contour cultivated land produces less runoff than up and down slope cultivation
- A terraced farmland produces less runoff compared to unterraced farmland
- Cultivated farmlands with organic fertilizer and mulching produce less runoff

With this background, then, the purpose of this section is to provide proper indicators for estimating runoff in view of the design of SWC techniques, and thus minimize erosion.

2.3 Runoff Estimation

2.3.1 Runoff rate

The runoff rate most commonly referred to as the **peak runoff rate is the maximum expected runoff rate from the maximum rainfall of a given period of time.**

If you are designing a disposal structure for a period of 10 years, then the design peak runoff rate is the maximum runoff expected from the highest rainfall in the 10 years period.

2.3.2 Points to be considered in estimating runoff

Runoff is part of the rainfall that does not infiltrate into the soil but moves down slope to join streams, rivers and lakes. Thus, it can analytically be represented as

Runoff = Rainfall - Infiltration

If you are working in a place where, for instance the soils have good infiltration capacity, then you can consider that 50% of the rainfall infiltrates into the soil and the runoff expected in this case is 50% of the rainfall.

Suppose the daily maximum rainfall recorded for five years period for a given locality is, year 1 (25mm), year 2 (48mm), year 3 (85mm), year 4 (60mm) and for year 5 (55mm).

Then the runoff is calculated from the maximum daily rainfall and this is the design runoff

> Runoff = Rainfall - Infiltration = 85 mm - 50% of 85 mm = 42. 5mm

The runoff is 42.5 mm. The runoff in this case is expressed in terms of depth of water.

Runoff expressed in terms of depth is not convenient to determine the capacity of disposal structures. If you are planning to design a channel to discharge a given amount of runoff or a spillway, then you ought to know how much of the runoff could be accommodated/ evacuated by that channel. Therefore, you have to know what quantity of the water has to be conveyed and at what rate. **That is the reason why it is compulsory to determine the peak runoff rate.**

The reason why the peak runoff rate is used to determine the capacity of channels is to avoid risk of designing low or high capacity channels, rupture and overtopping of dams, overflow bunds and rainfall multiplier systems. For instance low capacity channels would not be required since they allow overtopping and high capacity channels are not required either, because they entail unnecessary costs.

2.3.3 Estimating runoff from a small catchment area

(i) Cook's method

The size of the catchment area which is often called runoff area can be measured either from a map or surveyed in the field itself, or usually estimated. Runoff is influenced by various factors which are generally referred to as surface conditions. Surface conditions which affect runoff are the vegetative cover, soil conditions and the slope/topography.

Therefore, for estimating runoff, the role played by each of these factors has to be valued. Values for surface conditions are given in the following table.

Vegetative Cover	Value	Soil conditions	Value	Topography (slope)	Value
Forest or thick grass cover	10	Well drained soils, i.g sandy	10	Slope 0-5%	5
Scrub or medium grass cover	15	Moderately pervious soils e.g. silt	20	Slope 5-10%	10
Cultivated land	20	Slightly pervious soils e.g. loams	25	Slope 10-30%	15
Bare or sparse cover	25	Shallow soils with impeded drainage	30	Slope > 30%	20
		Clay sticky soils and rocky areas	35-40	Mountainous	25

Table 1 Values for surface conditions

From each of the three columns above, the most appropriate values should be selected and added to give the summarised characteristics.

Exercise 1 Find summarised characteristics

Find the summarised characteristics for a land with the following surface conditions: The land is cultivated, having a loam soil on a 20% slope. Summarised characteristics of the land would therefore be:

Solution: For cultivated land the value under the column vegetation, for a cultivated land is 20, from the second column of soil conditions you have the value of 25 for loam soils and from the third column of topography you have the value of 15 for a 20% slope. Thus the summarised characteristics = 20 + 25 + 15 = 60

After having decided the summarized characteristics value, then the runoff in cubic meters per second (m^3/sec) can be read from the table given below. The values for runoff is given in Table 2.

Runoff area (ha)	Summarized Characteristics of the runoff area									
	30	35	40	45	50	55	60	65	70	75	80
2	0.1	0.2	0.3	0.3	0.4	.04	0.5	0.5	0.6	0.7	0.8
4	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.1	1.3	1.5
6	0.3	0.4	0.6	0.7	0.8	1.1	1.2	1.4	1.6	1.9	2.1
8	0.4	0.6	0.7	0.8	1.1	1.3	1.6	1.8	2.1	2.4	2.7
12	0.5	0.7	0.9	1.2	1.5	1.8	2.2	2.5	3.0	3.4	3.8
16	0.6	0.8	1.1	1.4	1.8	2.3	2.7	3.1	3.7	4.2	5.0
20	0.7	1.0	1.4	1.8	2.3	2.8	3.4	4.0	4.7	5.7	6.1
30	1.0	1.4	2.0	2.5	3.3	4.0	4.8	5.7	6.7	7.6	8.8
40	1.1	1.5									
50	1.2	1.8									

Table 2 Runoff values in cubic meters per second

The runoff values in the above table are valid for a square runoff area.

Exercise 2 Find the runoff to be produced from a catchment with a square runoffarea of 20 hectares with the summarised calculated in exercise 1.

Solution: Use Table 2 to read the runoff in cubic meters per second.

Runoff area = 20 ha, summarised characteristics from the preceding exercise is 60.

Then from Table 2 read the value of 3.4 corresponding to the value of 20 for area and the value of 60 for summarised characteristics. Then, runoff (Q) from the Table 2 is 3.4 cubic meters per second (m^3/sec).

Now you are able to roughly estimate the runoff to be expected from a given area. What follows then is to design the size of a channel/spillway that can adequately accommodate the runoff estimated (see Part 5 on cutoff drains/waterways and gully control measures).

It should be noted that Cooks' method is rather imprecise and should be used with caution. The rainfall intensities used in this case to extrapolate the data in table 2 range from 75-100 mm, and thus quite safely within the maximum peak rainfall intensities likely to occur. However, higher intensities may easily occur under Dry Zone conditions and thus the data included in table 2 should be used with care. Therefore, if the Cook s method is applied, add 10-20% for safety purposes to the runoff values indicated in the table.

However, for larger catchments and for better accuracy, the **Rational method described below for runoff estimation is strongly recommended.**

(ii) Rational method

The estimation of runoff by using the rational method is given by $Q = \frac{KIA}{36}$

Where:

Q = the peak runoff rate or the design discharge (m^3/sec)
K = the runoff coefficient
I = the rainfall intensity (cm/hour)
A = the runoff producing area

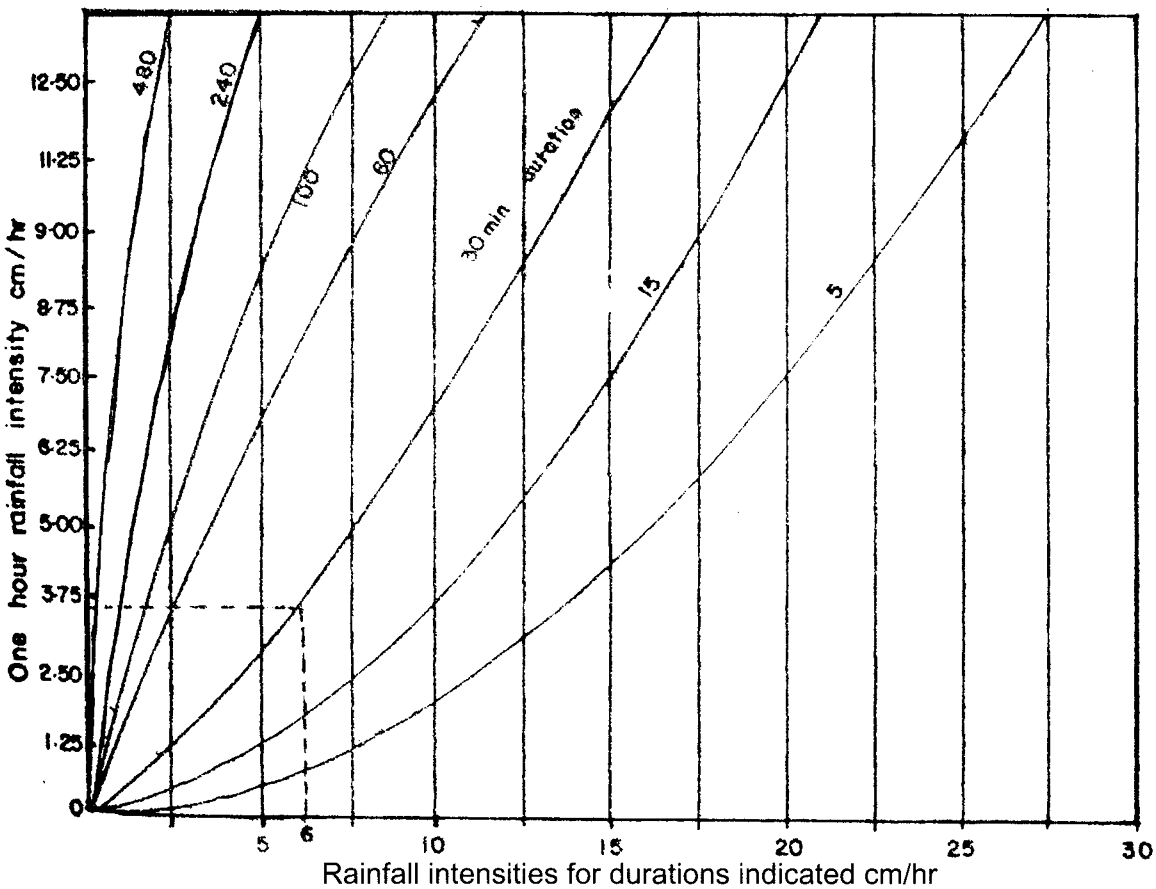


Figure 1 Relationships between an hourly and other duration intensities

Land Use / Cover	Runof Coefficient		
	Slope (0-5%)	Slope (5-10%)	Slope (10-30%)
CULTIVATED LAND			
• Open Sandy loam	0.25-0.30	0.40	0.52
• Clay & Silt loam	0.50	0.60	0.72
• Tight Clay	0.60	0.70	0.82
PASTURES			
• Dense cover	0.1	0.16	0.22
• Medium cover	0.3	0.36	0.42
• Open pastures	0.4	0.55	0.60
FOREST/WOODLAND			
• Dense cover	0.10	0.25	0.30
• Medium cover	0.30	0.35	0.50
• Scattered	0.40	0.50	0.60

Table 3 Values of Runoff Coefficient (tentative)

Exercise 3 Find the runoff rate using the rational method for a runoff producing area of 80 ha of cultivated land having clay soils on a land slope of 8%. Assume the rainfall of 3.75 cm/hour. And also assume the time of concentration of 30 minutes.

Solution:

K from table 3 for clay soil and slope 8%, K = 0.60

I_{30} is around 6 cm/hr by using the relationship given in the graph for the design intensity.

A is the drainage area of 80 ha.

Therefore Q = (0.6 x 6 x 80)/36 = 8 m^3/sec

3. FOOD, FORAGE AND TREE CROPS WATER REQUIREMENTS FOR SOIL AND WATER CONSERVATION

In dry areas, two main strategies for soil and water conservation are envisaged based upon crop water requirements.

STRATEGY 1

IN AREAS WHERE **PRECIPITATION IS INSUFFICIENT TO MEET CROPS WATER REQUIREMENTS** (ERRATIC RAINS FREQUENT, DROUGHT RISKS HIGH, LOW RAINFALL, ETC.) OR IN CASE YOU WANT TO INTRODUCE CROPS HAVING HIGHER WATER REQUIREMENTS => **SELECT SWC METHODS ABLE TO INCREASE WATER AVAILABILITY, IMPROVE ITS UTILIZATION/DISTRIBUTION AND SAFE DISPOSAL OF EXCESS RUNOFF (IF ANY)**

Most of the measures described in this case are using the **"RAINFALL MULTIPLIER"** effect, meaning measures designed to include a run-off area (microcatchment) serving or supplying additional water to a run-on area (cultivated area). The soil and water conservation methods to apply are also known as **WATER HARVESTING MEASURES, i.e. THE COLLECTION OF RUNOFF WATER FOR PRODUCTIVE PURPOSES.**

Water harvesting measures include also reservoirs of different types (cisterns, ponds, dams, etc.) that collect water from external macro-catchment for irrigation or domestic & livestock uses. These specific measures are not treated here since they are beyond the scope of this guideline.

Therefore, for practical reasons, "rainfall multiplier systems" are confined here to those measures which are using internal or external catchments to supply additional water to crops and, at the same time, control erosion.

- The scope of rainfall multiplier systems is to increase production levels in one portion of the total area or to introduce crops with higher water requirements that otherwise would not grow without additional moisture. **The measures should be seen as a potential for abandoned lands or lands considered impossible to cultivate because of severe rainfall deficits.** If whatever portion of this land, even half or less of it, is rehabilitated it will be seen by the users as a gain compared with nothing before. The advantage of such measures are clearly seen under those conditions.
- **Differently, the application of rainfall multiplier systems in already cultivated areas may be seen as a constraint and reduction of arable land,** even if the total product received from the run-on/cultivated area exceeds the total product obtained by the whole area cultivated under normal conditions. Then, field experts should be very careful in selecting rainfall multiplier systems for those areas and, if so, carefully select the ratio between the area yielding run-off and the cultivated area. Different designs should be tried at small scale first during a few years, by comparing production performance using different ratios and site locations.

Before rainfall multiplier systems are applied, relevant information on crop water requirements, design rainfall, efficiency factor and runoff coefficients must be known.

3.1 Water Requirements of Crops

Different methods exist to determine water requirements for specific plants. In absence of any measured climatic data it is often correct to use estimates of water requirements for common crops and add or reduce requirements of other plants based on the climatic and soil type conditions. For instance, it is clear that sorghum and millet growing in semi-arid areas will have less water needs than the same crop growing in drier conditions (hot winds, higher temperatures, etc.).

Crop	Crop water need (mm/total growing period)
Beans	300 - 500
Citrus	900 - 1200
Cotton	700 - 1300
Groundnut	500 - 700
Maize	500 - 800
Sorghum / Millet	450 - 650
Soybean	450 - 700
Sunflower	600 - 1000

Table 4 Approximate values of seasonal crop water needs

It was therefore preferred to take a certain standard crop or reference and determine how much water this crop needs per day in the various climatic regions. As a standard crop a grass has been chosen.

Climatic factor	Crop water need High	Low
Sunshine	Sunny (no clouds)	cloudy (no sun)
Temperature	hot	cool
Humidity	low (dry)	high (humid)
Windspeed	windy	little wind

Table 5 Effect of major climatic factors on crop water needs

Table 6 shows the average daily water needs of this reference grass crop depending on the rainfall regime and temperatures.

Climatic zone	Mean daily temperature		
	low (<15°C)	medium (15-25°C)	high (>25°C)
Desert/arid	4-6	7-8	9-10
Semi-arid	4-5	6-7	8-9

Table 6 Average daily water needs for standard grass during irrigation season

For the various crops it is possible to determine how much water they need compared to the standard grass.

-30%	-10%	same as standard grass	+10%	20%
Citrus Olives	Squash	Crucifers Groundnuts Melons Onions Peppers Grass Clean cultivated nuts & fruit trees	Barley Beans Maize Cotton Lentils Millet Safflower Sorghum Soybeans Sunflower Wheat	Nuts & fruit trees with cover crop

Table 7 Crop water needs in peak period of various crops compared to the standard grass crop

The influence on crop water requirements of the crop type and the length of the growing period (not only daily needs) is very important.

Crop	Total growing period (days)	Crop	Total growing period (days)
Alfalfa	100 - 365	Melon	120 - 160
Barley/Oats/		Millet	105 - 140
Wheat	120 - 150	Onion,green	70 - 95
Bean,green	75 - 90	dry	150 - 210
dry	95 - 110	Pepper	120 - 210
Citrus	240 - 365	Rice	90 - 150
Cotton	180 - 195	Sorghum	120 - 130
Grain/small	150 - 165	Soybean	135 - 150
Lentil	150 - 170	Squash	95 - 120
Maize,sweet	80 - 110	Sunflower	125 - 130
grain	125 - 180		

Table 8 Indicative values of the total growing period

It is also relevant to have an idea about the different response of crops to moisture deficits. This characteristic is called drought resistance .

Group one:	(low sensitivity)	Groundnuts Safflower
Group two:	↓	Sorghum Cotton Sunflower
GroupThree:	↓	Beans
Group Four:	(high sensitivity)	Maize

Table 9 General sensitivity to drought

Calculation of Crop Water Requirements

ET crop = Kc x ETo

ET crop = the water requirement of a given crop in mm per unit of time (mm/day, mm/month, mm/season)

Kc = crop factor

ETo = the reference crop evapotranspiration in mm/unit of time (mm/day, mm/month, mm/season)

Indicative values for ETo which may be used in absence of measured and calculated figures:

Climatic zone	Mean daily temperature		
	15œ	15-25œ C	25œ
Desert/arid	4-6	7-8	9-10
Semi-arid	4-5	6-7	8-9
Sub-humid	3-4	5-6	7-8
Humid	1-2	3-4	5-6

Table 10 Indicative values of ETo (mm/day)

The crop factor varies according to the growth stage of plants:

- initial stage: when the crop uses little water;
- the crop development stage, when water consumption increases;
- the mid-season stage, when water consumption reaches a peak;
- the late season stage, when the maturing crop requires less water.

Crop	Initial stage	(days)	Crop dev. stage	(days)	Mid-season stage	(days)	Late season	(days)	Season average
Cotton	0.45	(30)	0.75	(50)	1.15	(55)	0.75	(45)	0.82
Maize	0.40	(20)	0.80	(35)	1.15	(40)	0.70	(30)	0.82
Millet	0.35	(15)	0.70	(25)	1.10	(40)	0.65	(25)	0.79
Sorghum	0.35	(20)	0.75	(30)	1.10	(40)	0.65	(30)	0.78
Grain/small	0.35	(20)	0.75	(30)	1.10	(60)	0.65	(40)	0.78
Legumes	0.45	(15)	0.75	(25)	1.10	(35)	0.50	(15)	0.79
Groundnuts	0.45	(25)	0.75	(35)	1.05	(45)	0.70	(25)	0.79

Table 11 Crop factors (Kc)

Since the values for ETo are measured or given on a daily basis (mm/day), an average value for the growing season has to be determined and then multiplied with the average seasonal crop factor Kc as given in the last Table 11.

Exercise on crop water requirements

Crop to be grown: Sorghum

- length of total growing season: 120 days (sum of all 4 crop stages according to Table 11)
- ETo: average of 6.0 mm/ day over the total growing season (from measurement, calculation or Table 10)

Crop water Requirement:

ETo crop = kc x ETo

ETo crop = 0.78 x 6 = 4.68 mm per day

ETo crop = 4.68 x 120 days = approx. 560 mm per total growing season

3.2 Water Requirements of Trees, Rangeland and Fodder

Information on water requirements for multipurpose and fruit trees is scarce, specially when applied to runoff water harvesting systems. Normally trees are sensitive to moisture stress during establishment stage and can withstand long periods of drought in their adult stage. In this guideline, rainfall multiplier systems for tree planting are described in detail, although design principles should not be only dictated by assumptions on water requirements but also on spatial arrangements, water harvesting capacity of the conservation device, sensitivity to waterlogging and land users desire.

	Semi-arid marginal 500-900 mm rain	Arid/semi-arid 150-500 mm rain	Tolerance to temporary waterlogging
Acacia albida	yes	yes	yes
A. nilotica	yes	yes	yes
A. saligna	no	yes	yes
A. senegal	yes	yes	no
A. seyal	yes	yes	yes
A. tortilis	yes	yes	no
Albizia lebbeck	yes	no	no
Azadirachta indica	yes	no	some
Balanites aegyptiaca	yes	yes	yes
Cassia siamea	yes	no	no
Casuarina equisetifolia	yes	no	some
Colophospermum mopane	yes	yes	yes
Cordeauxia edulis	no	yes	?
Cordi sinesis	no	yes	?
Delonix elat	yes	no	?
Eucalyptus camaldulensis	yes	yes	yes
Prosopis chilensis	yes	yes	some
Prosopis cineraria	yes	yes	yes
Prosopis juliflora	yes	yes	yes
Ziziphus mauritiana	yes	yes	yes

Table 12 Naturally preferred climatic zones of multipurpose trees

Species	Seasonal water requirement	Place	Source
Appricots	550 mm*	Israel	Finkel (1988, quoting Evanari)
Peaches	700 mm*	Israel	Finkel (1988, quoting Evanari)
Pomegranate	265 mm	Israel	Shanan and Tadmore (1979)
Jujube (Ziziphus mauritiana)	550-750 mm	Israel	Shanan (1986)

Table 13 Fruit trees water requirements

Water requirements of rangeland and fodder are not usually calculated. Only few countries have accurate data (Australia, USA) and in semi-arid and arid areas of developing countries, water harvesting for forage improvement is estimated empirically, based on the grass reference crop or on local knowledge.

3.3 Design Model for Rainfall Multiplier and Water Harvesting Systems

Each rainfall multiplier and water harvesting system consists of a catchment (collection) and a cultivated (concentration) area. The relationship between the two, in terms of size, determines by what factor the rainfall will be multiplied . For an appropriate design of a system, it is recommended to determine the ratio between catchment (C) and cultivated (CA) area.

Many successful water harvesting systems (WH) have been established by merely estimating the ratio between catchment and cultivated area. This may indeed be the only possible approach where basic data such as rainfall, runoff and crop water requirements are not known. However, calculation of the ratio will certainly result in a more efficient and effective system provided the basic data are available and accurate.

Nevertheless, it should be noted that calculations are **always based on parameters with high variability.** Rainfall and runoff are characteristically erratic in regions where WH is practised. Therefore, it is sometimes necessary to modify an original design in the light of experience, and often it will be useful to incorporate safety measures, such as cut-off drains, to avoid damage in years when rainfall exceeds the design rainfall.

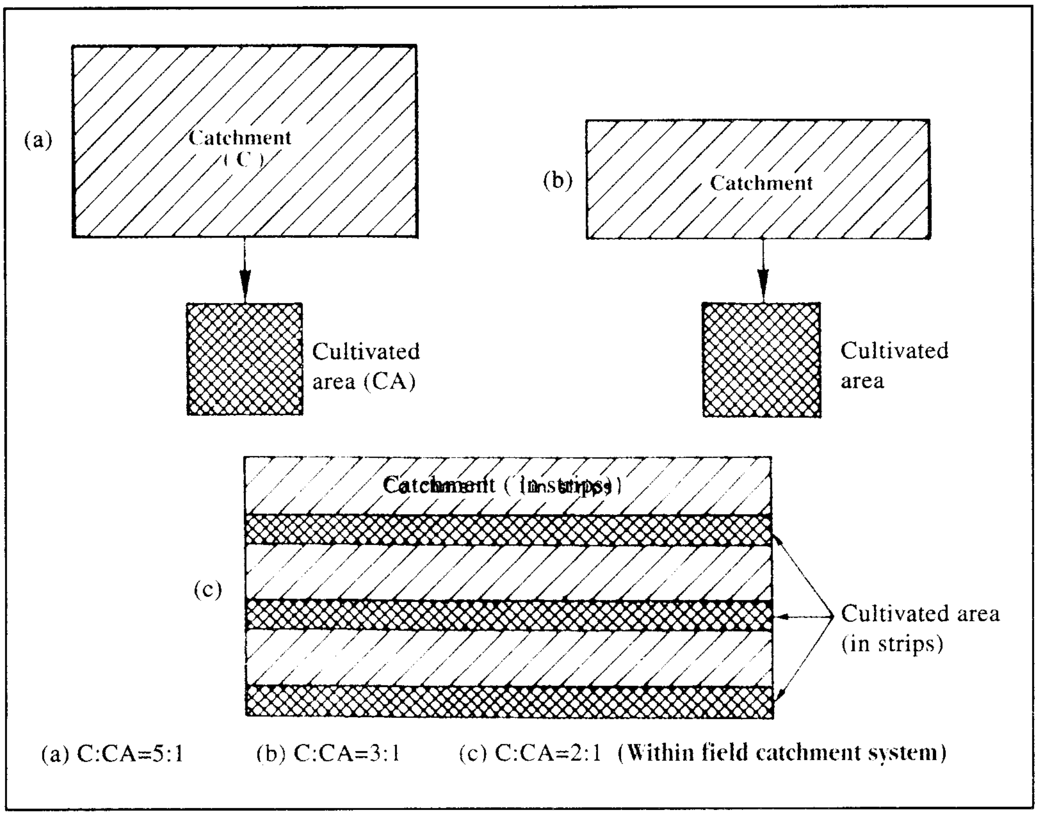
The calculation of C:CA ratio is primarily useful for WH systems where crops are intended to be grown.

3.3.1 Rainfall multiplier and WH systems for crop production

The calculation of the catchment : cultivated area ratio is based on the concept that the design must comply with the rule:

WATER HARVESTED = EXTRA WATER REQUIRED

l-B



(Catchment: cultivated area ratio- The Principle)

The amount of water harvested from the catchment area is a function of the amount of runoff created by the rainfall on the area. This runoff, for a defined time scale, is calculated by multiplying a design rainfall with a runoff coefficient. As not all runoff can be efficiently utilized (because of deep percolation losses, etc.) it must be additionally multiplied with an efficiency factor.

WATER HARVESTED = CATCHMENT AREA X DESIGN RAINFALL X RUNOFF COEFFICIENT X EFFICIENCY FACTOR

The amount of water required is obtained by multiplying the size of the cultivated area with the net crop water requirements which is the total water requirement less the assumed design rainfall.

EXTRA WATER REQUIRED = CULTIVATED AREA X (CROP WATER REQUIREMENT - DESIGN RAINFALL)

By substitution in our original equation

WATER HARVESTED = EXTRA WATER REQUIRED

we obtain:

CATCHMENT AREA X DESIGN RAINFALL X RUNOFF COEFF. X EFF. FACTOR = CULTIVATED AREA X (CROP WATER REQUIREMENT - DESIGN RAINFALL)

If this formula is rearranged we finally obtain:

$$\frac{\text{CROP WATER REQUIREMENT - DESIGN RAINFALL}}{\text{DESIGN RAINFALL X RUNOFF COEFF. X EFF. FACTOR}} = \frac{\text{CATCHM. AREA}}{\text{CULTIV. AREA}}$$

Elements of the formula

Crop Water Requirement

Crop water requirement depends on the kind of crop and the climate of the place where it is grown (see estimates in above tables).

Design Rainfall

The design rainfall is set by calculations or estimates. It is the amount of seasonal rain at which, or above which, the system is designed to provide enough runoff to meet the crop water requirement. If the rainfall is below the design rainfall, there is a risk of crop failure due to moisture stress. When rainfall is above the design , then runoff will be in surplus and may overtop the bunds.

Design rainfall is calculated at a certain probability of occurrence. If, for example, it is set at a 67% probability, it will be met or exceeded (on average) in two years out of three and the harvested rain will satisfy the crop water requirements also in two out of three years.

A conservative design would be based on a higher probability (which means a lower design rainfall), in order to make the system more reliable and thus to meet the crop water requirements more frequently. However the associated risk would be a more frequent flooding of the system in years where rainfall exceeds the design rainfall.

The design rainfall is determined by means of a statistical probability analysis.

Probability analysis

The first step is to obtain annual rainfall totals for the cropping season from the area concerned. It is important to obtain long term records (10 years).

In the following example, 32 annual rainfall totals from Mogadishu (Somalia) were used for the analysis.

Year	R mm	Year	R mm	Year	R mm	Year	R mm	Year	R mm
1957	484	1964	489	1971	271	1977	660	1983	273
1958	529	1965	498	1972	655	1978	216	1984	270
1959	302	1966	395	1973	371	1979	594	1985	423
1960	403	1967	890	1974	255	1980	544	1986	251
1961	960	1968	680	1975	411	1981	563	1987	533
1962	453	1969	317	1976	339	1982	526	1988	531
1963	633	1970	300						

Table 14 Annual rainfall, Mogadishu (Somalia)

The next step is to rank the annual totals from Table 11 with m = 1 for the largest value and m = 32 for the lowest value and to rearrange the data accordingly (Table 15).

The probability of occurrence P (%) for each of the ranked observations can be calculated (columns 4, 8, 12, 16, Table 15) from the equation:

$$P(\%) = \frac{m - 0.375}{N + 0.25} \quad X\ 100$$

Where: P= probability in % of the observation of the rank m
m= the rank of the observation
N= total number of observations used

Year	R mm	m	p %	Year	R mm	m	p %	Year	R mm	m	p %	Year	R mm	m	p %
1961	960	1	1.9	1988	531	11	32.9	1966	395	21	64.0	1986	251	31	95.0
1967	890	2	5.0	1958	529	12	36.0	1973	371	22	67.1	1978	216	32	98.1
1968	680	3	8.1	1982	526	13	39.1	1976	339	23	70.2				
1977	660	4	11.2	1965	498	14	42.2	1969	317	24	73.3				
1972	655	5	14.3	1964	489	15	45.3	1959	302	25	76.4				
1963	633	6	17.4	1957	484	16	48.4	1970	300	26	79.5				
1979	594	7	20.5	1962	453	17	51.6	1983	273	27	82.6				
1981	563	8	23.6	1985	423	18	54.7	1971	271	28	85.7				
1980	544	9	26.7	1975	411	19	57.8	1984	270	29	88.8				
1987	533	10	29.8	1960	403	20	60.9	1974	255	30	91.1				

Table 15 Ranked annual rainfall data, Mogadishu (Somalia)

The above equation is recommended for N = 10 to 100 (Reining et al. 1989). There are several other, but similar, equations known to compute experimental probabilities.

The next step is to plot the ranked observations (columns 2, 6, 10, 14, Table 15) against the corresponding probabilities (columns 4, 8, 12, 16, Table 15). For this purpose normal probability paper must be used (see figure).

Finally a curve is fitted to the plotted observations in such a way that the distance of observations above or below the curve should be as close as possible to the curve (see figure). The curve may be a straight line.

From this curve it is now possible to obtain the probability of occurrence or exceedance of a rainfall value of a specific magnitude. Inversely, it is also possible to obtain the magnitude of the rain corresponding to a given probability.

In the above example, the annual rainfall with a probability level of 67 percent of exceedance is 371 mm (see figure), i.e. on average in 67 percent of time (2 years out of 3) annual rain of 371 mm would be equalled or exceeded.

For a probability of exceedance of 33 percent, the corresponding value of the yearly rainfall is 531 mm.

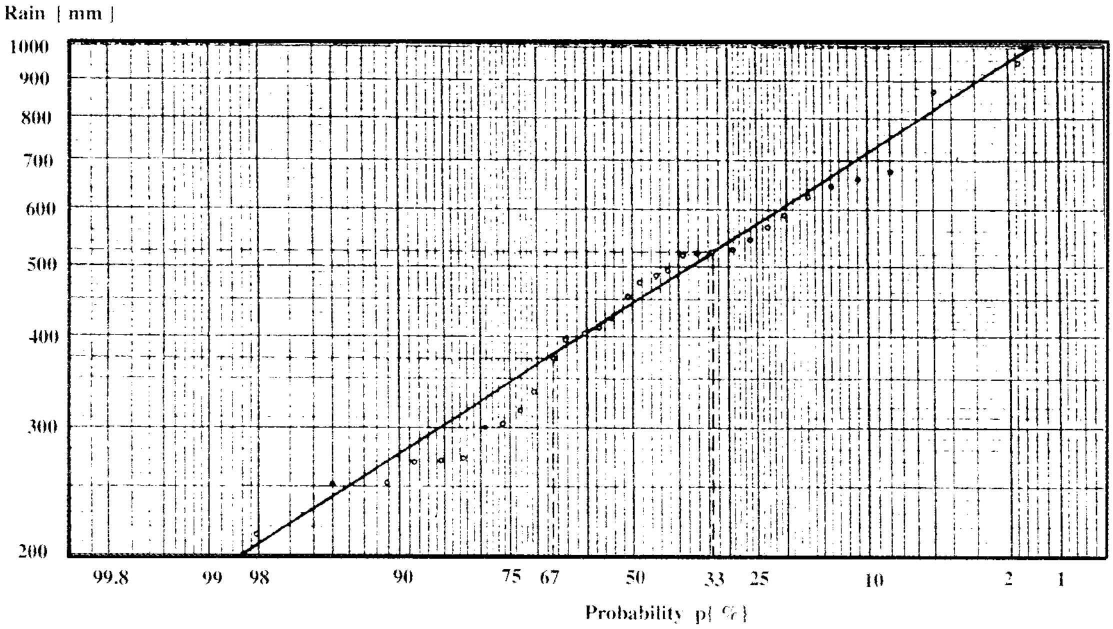


Figure 2 Probability diagram with regression line for an observed series of annual rainfall totals - Mogadishu, Somalia

The return period T (in years) can easily be derived once the exceedance probability P (%) is known from the equations.

$$T = \frac{100 \text{ (years)}}{P}$$

From the above examples the return period for the 67 percent and the 33 percent exceedance probability events would thus be:

$$T67\% = \frac{100}{67} = 1.5 \text{ years}$$

i.e. on average an annual rainfall of 371 mm or higher can be expected in 2 years out of 3; and

$$T33\% = \frac{100}{33} =$$

3 (years) respectively, i.e. on average an annual rainfall of 531 mm or more can only be expected in 1 year out of 3.

Runoff Coefficient

This is the proportion of rainfall which flows along the ground as surface runoff. It depends amongst other factors on the degree of slope, soil type, vegetation cover, antecedent soil moisture, rainfall intensity and duration. The coefficient ranges tentatively usually between 0.2 and 0.7 (see runoff analysis). When measured data are not available, the coefficient may be estimated from experience.

Efficiency Factor

This factor takes into account the inefficiency of uneven distribution of the water within the field as well as losses due to evaporation and deep percolation. Where the cultivated area is levelled and smooth the efficiency is higher. Microcatchment systems have higher efficiencies as water is usually less deeply ponded. Selection of the factor is left to the discretion of the designer based on his experience and of the actual technique selected. Normally the factor ranges between 0.5 and 0.75.

Examples on how to calculate the ratio C:CA

Climate: Semi- Arid
RWH system: External Catchment
Crop: 110 day Sorghum

- **Crop Water Re quirement = 525 mm**
- **Design rainfall = 375 mm (P=67%)**
- **Runoff Coefficient = 0.25**
- **efficiency factor = 0.5**

$$\frac{C}{CA} = \frac{525-375}{375x0.25x0.5} = 3.2$$

i.e The catchment area must be 3.2 times larger than the cultivated area. In other words, the catchment: cultivated area ratio is 3.2:1

Comment: A ratio of a approximately 3:1 is common and widely appropriate.

3.3.2 Rainfall multiplier & WH systems for trees

The ratio between catchment and cultivated area is difficult to determine for systems where trees are intended to grow. As a rule of thumb, it can be assumed that the area to be exploited by the root system is equal to the area of the canopy of the tree. A similar equation as the one used for crops is possible to apply. However, for practical reasons, the size of the catchment area for multipurpose and fruit trees in dry areas should range between 10 to 30 square meters (Myanmar conditions). C:CA ratios recommended are 1:4-1:8 depending on the type of tree, its future size and the soil type conditions.

3.3.3 Rainfall multiplier & WH systems for rangelands and fodder

In most cases, C:CA ratios are not calculated. As a general guideline a ratio of 1:1 to 10:1 is applied based upon the level of aridity.

STRATEGY 2

WHERE RAINFALL IS BARELY SUFFICIENT TO MEET CROP WATER REQUIREMENTS ==> **METHODS FOCUSSING ON MAXIMUM WATER RETENTION**, INCREASE SOIL PROFILE MOISTURE STORAGE CAPACITY AND EVENTUALLY EVACUATION OF EXCESS WATER.

This second strategy apply to most of the cultivated lands in the Myanmar Dry Zone. Although climatic risks are high, farmers would not accept to leave part of their fields as a runoff area. The strategy then would focus on methods able to capture rainfall and make the best use of it, i.e. increase the storage capacity of the soil and infiltration, avoid soil and water losses by runoff, and reduce evapotranspiration.

They rain may not be sufficient every year to grow crops but crop failure is occurring frequently because a consistent part of rainfall is being lost as runoff and infiltration within soil profile is limited. With conservation measures, besides controlling erosion, most of the rainfall would be retained and used by the crops effectively. Even in case of low rainfall and periods of drought, not all crops may fail and a certain amount of yield may be ensured.

Similarly, even when total rainfall is considered sufficient but some of the crops are reported to have failed due to long gaps between successive showers, conservation devices can play a mitigating role. In this case, conservation works help to partially or totally overcome these gaps by retaining all rainfall water within the plot.

Most of the rainfall and runoff analysis data described above are also useful in this case, to design stable and durable structures, and indicate the need for the provision of excess water disposal measures (spillways on bunds, cutoff drains and waterways above the cultivated area, etc.).

Since all rainfall should be trapped, main focus would be directed to the assessment of the soil and topographic conditions that will determine both the type, spacing, construction standards and management requirements of each single or combined SWC measure.

In dry zones, the positioning & layout of soil and water conservation structures in the field mostly follow Contour line since the main objective is to trap water first and second, to avoid crops to be damaged by excess runoff. The retaining of soil is appreciated but not usually considered as a first priority. The climatic variability in dry lands make the choice of measures a difficult exercise.

However, in some years of relative abundance of rainfall, waterlogging and damage to the structures may occur, forcing farmers to spend time for repairs and loosing some yield. In this case, bunds with spillways may be a suitable option. It is always strongly recommended to allow the land user to weight the pro and cons of the measure and decide its adoption accordingly. It is of no use to force him at the beginning, and few years later observe that all the work done has been destroyed.

The techniques and instruments used for the layout of structures will be explained in Part 5, during the description of the different SWC measures for each land use type.

Concluding, this section provides information on the behavior of rainfall and the erosion risks due to runoff. It also provides guidance on the SWC strategy to adopt based upon climatic conditions, soil types and crop water requirements.

4. DESCRIPTION OF SOILS AND TOPOGRAPHY

This section is an attempt to elaborate a systematic approach for assessing soil and land characteristics in view of their utilization for determining soil and water conservation packages. The intention is improve field staff s perceptions and knowledge about soils and topography so that they would easily and comprehensively recognize the linkages with farmers problems and their interrelation. Ultimately, it would be possible to link each soil and water conservation package to both bio-physical and socio-economic conditions once testing and effectiveness of the different packages would be demonstrated. However, the land classification system explained in this section is a first preliminary effort along these lines and should be considered with flexibility and used with care.

4.1 Understanding Soils in Relation to Soil and Water Conservation

Information on **soil properties and qualities are essential to design soil and water conservation measures.** Soil texture, stoniness, structure, reaction, organic matter content, depth and infiltration capacity are key factors that influence erodibility and fertility, and thus the selection of conservation measures. This section will highlight the soil properties in relation to their use in a land classification system for use in soil and water conservation. Moreover, main **topographic factors** such as slope gradient and length are also integral part of the soil & landscape survey.

A systematic way to organize the above information for use in the selection of SWC techniques is through a system of land classification (LCS). This system should not be confused with the Land Capability Classification of the US Department of Agriculture, although most of its principles are valid here. Similarly, some elements of the land classification system for use soil conservation described in this section are inspired from the Land Evaluation System developed by FAO which involves rating the suitability of land for a range of potential uses by matching their qualities and characteristics. In our case, the suitability of the land can be modified by soil and water conservation measures and improved drainage.

The following sections would highlight a possible LCS for the Myanmar Dry Zone that should be further tested, refined and improved based upon local conditions. It is however an useful exercise, leading field technicians to understand the interrelationships between the different soil and topographic factors within a given land use. Besides, it provides a framework to identify key physical constraints and guidance on the selection and design of conservation measures. For **this purpose the first draft of a Land Classification System for use in soil and water conservation for the Myanmar Dry Zone is outlined in this guideline. In absence of sufficient time, equipment and skills available to undertake a LC exercise, proceed with the usual simple method** of assessing each land use unit, and their sub-units based on slope ranges, soil depth, textural classes and any other relevant factor. **In the village level planning guideline, a simple and practical description of soils and landscape units** is suggested for use by extension staff not trained in particular advanced systems of land classification.

4.2 The Land Classification System for Use in Soil and Water Conservation

4.2.1 Introduction

In many areas of the country excessive population pressure have led to the cultivation of steep slopes and/or shallow soils in spite of these lands not being capable of supporting sustained agriculture. In other areas overgrazing takes place on already severely eroded lands under the pressure of a high number of cattle and depletion of forest resources.

It is clear that the reduction of good potential land and the increase of population forces people to use more and more land beyond its capability in order to meet their needs.

HOW CAN WE ARRANGE SUSTAINED AGRICULTURE WITHOUT CAUSING FURTHER SOIL DEGRADATION IN THE MYANMAR DRY LANDS WHICH ARE CURRENTLY AFFECTED BY HIGH POPULATION PRESSURE AND LACK OF UNEXPLOITED LAND RESOURCES ?

Certainly, the answer is not only in the hands of soil conservationists alone, and would necessarily require the interaction and involvement of policy makers, technical experts and land users. Nevertheless, the contribution of the soil conservationist is to provide guidance and technical support not only to minimize soil erosion and land degradation but also to achieve sustainable agricultural production. In this respect, a land classification for soil and water conservation would help to find suitable range of technical options to optimize existing land use or changing it for the better in respect of both bio-physical and social requirements.

THEREFORE, THE WAY TO RATIONALIZE THE USE OF THE LAND AND TO APPLY THE APPROPRIATE SOIL AND WATER CONSERVATION MEASURES IS THROUGH THE A SYSTEM OF LAND CLASSIFICATION

The Land Classification is an interpretative system, the purpose of which is to group and classify areas of land with same capability to support sustained agriculture without resulting in land degradation.

The proposed **LAND CLASSIFICATION FOR USE IN SOIL AND WATER CONSERVATION** is based on the limited field experience gained so far during the current phase of project MYA/96/006 design and implementation of soil and water conservation activities. Ultimately, the range of characteristics of each land feature, which are used here to assess the land class units should be further tested in the field under different sub-agroecological systems before adopting the land classification system in the whole Dry Zone. Therefore, the soil and land characteristics given below are only indicative and should serve has a starting point for the preparation of a refined system for interpreting soils and landscape conditions meant to provide guidance in the selection of technical packages for soil and water conservation.

4.2.2 Principles

- The land classification is primarily meant for soil conservation purposes.
- The **land is classified mainly on the basis of limitations** (those directly or indirectly related to water erosion).
- The productivity assessment and the economic aspects are not considered in this classification but can easily be overlaid and provide guidance for more accurate and effective selection and design of SWC measures.
- The soil conservation requirement classes are homogeneous only with respect to the degree of limitations in agricultural use. Each class may include different kind of soils.
- To assess the classes, the range of diagnostic characteristics for each land feature is adapted to the physical and socio-economic conditions of the Myanmar Dry Zone.

4.2.3 Categories of the system

Two categories in the land classification are proposed:

THE SOIL CONSERVATION REQUIREMENT CLASSES (SCRC) represent the major category of the system. It is determined by the most limiting condition permitted in a range of characteristics for each land feature.

There are eight SCRC: I, II, III, IV, V, VI, VII, VIII

The risk of soil erosion increases through classes I to IV and VI to VIII, as well as the requirements for soil conservation practices and management. Class V is a special case: in this classification class V is wet land, very poorly drained; it has major management problems but no erosion hazard, unless by salts.

THE LAND CLASS UNIT (LCU) is the lowest category of the system. The major limiting factor affecting the use of the land for agricultural purposes determines the LAND CLASS UNIT.

The limiting factors could be one or two of the following land features: Slope (L), Soil depth (D), Past erosion (E), Waterlogging (W), Infiltration (I), Texture (T), and Stoniness & rockiness (S). Salinity (A), sodicity and pH or reaction (R), although important factors, are not considered as leading factors in this classification and their importance should be case specific and valued based upon local conditions (see page 79).

The symbol of the LAND CLASS UNITS are: SCRC symbol + Major Limiting Factor

Example of Land Class Units: IIL, IIIL, IVE, VIIIES

The land classification System for use in soil conservation also attempts to identify the MOST SUITABLE LAND USE for each Soil Conservation Requirement Class

The following grouping can be used:

SCRC	SUITABLE LAND USE
I	LAND SUITABLE FOR ANNUAL CROPS
II	
III	
IV	
V	WET LAND - REGULARLY WATERLOGGED, MAY BE SUITABLE ONLY FOR RICE & TEMPORARY GRAZING
VI	LAND SUITABLE FOR PERENNIAL CROPS OR GRAZING
VII	LAND SUITABLE FOR FORESTRY
VIII	LAND NOT SUITABLE FOR AGRICULTURE

Obviously the first group (classes I - IV) can also be suitable for grazing and forestry and the third group (class VI) can also be suitable for forestry. The Class V is a special class, it can be only suitable for temporary grazing, rice fields (based upon the quality of soils and reclamation) and for crops or trees resistant to a permanent very poor drainage. The figure below illustrates the suitable land use.

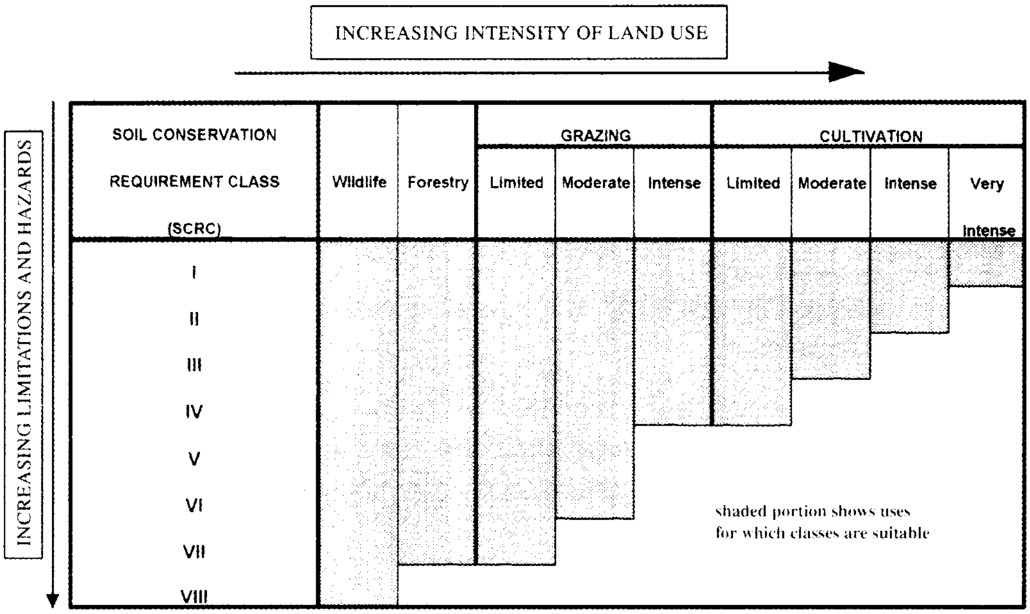


Figure 3

(i) Criteria for Land Classification:

The land classification criteria are based on the description of the range of characteristics of different soil & land features. The range of characteristics for each feature is adapted to the physical and socio-economic conditions of the Myanmar Dry Zone. The definitions for each range are given in a simple way to enable their assessment in the field.

For Land Classification the most important features to observe in the field are those directly or indirectly related with soil water erosion, such as: slope, soil depth, past erosion, infiltration, waterlogging, and stoniness or rockiness. Salinity and sodicity should be also assessed, at least empirically, since they influence the determination of the land class unit. Soil reaction or ph is difficult to assess except if soil analysis kits are available although soil conditions and some plant indicators may give technicians an approximate idea about the range of pH conditions. Recent soil analysis undertaken in a wide range of locations of the Dry Zone project areas shows most soils with pH > 8 and often above 8.5, denoting either important levels of salts or sodic conditions (Na > 15% in the CEC and pH > 8.5).

Slope (L)

The range of slopes given below, are those currently used for Soil Conservation purposes.

SLOPE CLASSES	% RANGE	CODE
Flat or almost flat	0-3	L1
Gently sloping	3-8	L2
Sloping	8-15	L3
Moderately steep	15-30	L4
Steep	30-50	L5
Very steep	> 50	L6

It is useful to be reminded that there is not always a relation between slope and/or soil depth and/or soil erosion. IT IS FREQUENTLY WRONGLY ASSUMED THAT ON FLAT

SLOPES DEEP SOILS ARE ALWAYS FOUND, AND THAT ON STEEP SLOPES THE SOILS ARE ALWAYS SHALLOW. Similarly, it is also not correct to assume that in flat or gentle slopes, erosion does not occur. In fact, as discussed in the erosion process section, this will depend on other factors such as erodibility of soils, erosivity of rainfall and vegetative cover. Regarding the occurrence of such situations many examples can be found

Soil Depth (D)

The soil depth includes the total depth of the soil to a contrasting layer significant for soil conservation requirements.

The soil depth can be limited by the presence or bedrock, hardpan, water table, or by a substratum which can affect soil conservation and management (e.g. soft or weathered rocks such as limestones, claystone, sandstones, marl, shales, schists, chalk, very gravely or stony substratum, etc.)

SOIL DEPTH CLASSES	cm	CODE
Very deep	> 150	D1
Deep	100-150	D2
Moderately deep	50-100	D3
Shallow	25-50	D4
Very shallow	<25	D5

The range of soil depth are those internationally used by the Soil Conservation Service - USA and FAO.

Past erosion (E)

It is very difficult to define classes when assessing past erosion in the field. The following descriptions may help field technicians in the assessment of past erosion.

EROSION CLASSES	DEFINITION	CODE
Nil	- No erosion noticeable	E0
Slight	- Some surface wash and small rills. Slight topsoil loss, no subsoil exposed. Tree/plants roots slightly exposed. Micropedestals observed in upper parts of the field.	E1
Moderate	-Rills cover most of the surface at regular intervals (after rain showers of medium/high intensity). Bleached spots in several parts of the field surface, much topsoil removed in upper portions of the field (coarser materials left). Pedestals 1-5 cm frequent. Occasionally, small patches of subsoil exposed. Double slopes observed as a result of continuous ploughing of rills. Tree/plant roots well exposed.	E2

Severe	- Shallow gullies frequent (occasionally deep ones). Most or all top soil removed, the surface layer almost entirely subsoil. Small areas of top soil remaining exposed. Occasionally, large stones on top of 10-50 cm pedestals. Tree roots almost completely exposed.	E3
Very severe	- Most of the land is dissected by gullies. Only small areas of top soil and upper subsoil are still present between the gullies. The land consists of exposed parent material or rock resulting from the complete removal of topsoil and subsoil.	E4

THE PAST EROSION ASSESSMENT MUST BE OBJECTIVE BY OBSERVING THE FEATURES DESCRIBED ABOVE AND NOT BY A SUBJECTIVE ASSUMPTION OF THE FACTS.

Texture (T)

Soil texture refers to the physical composition of the soil defined in terms of the relative proportion of sand, silt and clay.

The following textural classes are defined from field experience:

TEXTURAL GROUP	TEXTURAL CLASS	CODE
COARSE	Sand	T1
	Sandy loam	T2
	Loam	T3
MEDIUM	Silt loam	T4
	Clay loam	T5
FINE	Clay, Silt clay	T6
	Heavy clay	T7

Waterlogging (W)

Three field criteria may be utilised to assess waterlogging:

- Topographic position (depressions and flat areas are more susceptible to drainage problems).
- Mottling can be a sign of waterlogging, particularly if the mottle colour is grey, green, brown, yellow or red.
- Vegetation is a good indicator of drainage problems.

WATERLOGGING	DEFINITION	CODE
No waterlogging	Well drained soil	W0
Intermittently waterlogged	Imperfectly drained areas. Occupy level and sometimes depressed sites. Area is wet and waterlogged during the heavy rains for a few days/weeks. Brown or yellow mottles may occur in the profile (common on vertisols).	W1
Regularly waterlogged	Poorly drained areas. Occupy bottom lands, commonly flooded during the wet season and waterlogged for some time during the dry season. Color of the soil is predominantly grey with brown mottling.	W2
Swampy areas	Very poorly drained areas. Water table at or near the surface during the wet season. Soils are generally grey in colour.	W3

Infiltration (I)

The infiltration rate is function of the permeability, condition of soil surface (liability to capping, crusting, sealing) and the soil moisture content. The infiltration is influenced by the soil structure, salinity, sodicity and bulk density. The following descriptions will help the technicians to assess the infiltration in the field.

INFILTRATION CLASSES	DEFINITION	CODE
Good	The soil in the surface layer is porous or very permeable or has a good structure to absorb rapidly. When the dry soil is ploughed it breaks into fine clods and grains. Good plant cover or grasses are observed.	I0
Moderate	The soil in the surface layer has a massive structure or has a moderate to slow permeability. The surface has tendency to compact and seal. Crusts form rapidly after first showers. (*)	I1
Poor	In addition to a massive structure the soil has a strong tendency to seal on welting or settling to an almost impermeable crust on drying. When dry, the soil does not show cracks at the surface.	I2

(*) In this category the Vertisols and heavy clay soils located on gentle slopes are considered. Because of the cracks (during the dry season) and the good structure of the surface layer, the infiltration is good when the soil is dry but becomes poor when the soil is saturated.

Stoniness or rockiness (S)

Stony soils are less liable to erosion. The soil is not only protected by the stones but infiltration is increased as water flows into the soil around the edges of the stones; but the stones may interfere with tillage, specially with mechanized agriculture.

STONINESS CLASSES	ROCKINESS CLASSES	AREA COVER %	CODE
No stones or few	No rocks or few	< 15	S0
Moderately stony	Moderately rocky	15-30	S1
Stony	Rocky	30-50	S2
Very stony	very rocky	50-85	S3
Rubble land	rock outcrops	> 85	S4

Stones are the general term employed to define fragments >2mm:

gravel : < 7.5 cm
stones : 7.5-25 cm
boulders : > 25 cm

When the observations are being recorded in the ROCKINESS class, add to the code the symbol * (e.g. very rocky should be noted S2*)

Salinity and Sodicity

Salinity and sodicity in the Dry zone are rather common problems and would certainly play a great role in the selection of plant species and design of physical structures. They should be assessed through soil analysis (expensive) or, in most cases, empirical observations. For instance sodic soils disperse easily into water (observe dispersion by putting a clod of soil into a bucket of water) and have a massive, almost impermeable structure when dry. Moreover, sodic soils are prone to piping and tunnelling erosion. Salinity is easily observed by wetting and pasting a clod of soil and leaving it to dry for a day or so under the sun. If salts appear on the surface the soil is certainly saline. Other indicators are surface deposits of salts along drainage line banks, pooled water of reddish-brown color, etc. Additional assessment of the extent and levels of salinity and sodicity would be ascertained by asking farmers information about crops (stunt growth, saline indicator weeds/plants, etc.) and behaviour of soils when wet and dry and during tillage operations.

In most cases high levels of salinity and sodicity will affect the soil structure and influence the texture, infiltration and waterlogging factors which are already included in the system.

To determine exactly salinity and sodicity a soil laboratory analysis is required. In general, soils are:

- Saline soils when pH is < 8.5 and CEe (conductivity of the saturation extract) is > 4 mmho and ESP (sodium exchangeable percentage within cation complex) is < 15%.
- Sodic soils in the Myanmar dry zone (solonetz) when ESP is > 15% and pH is generally high (> 8.5) due to the presence of mono and bi Na carbonates.

- Soil reaction or pH (R)

pH	Type	Code
< 5	very acid	R0
5 - 6.5	acid	R1
6.5 - 7.5	neutral	R2
7.5 - 8.5	alkaline	R3
> 8.5	very alkaline	R4

- Salinity (A)

Conductivity	Type	Code
4 mmhos	low	A0
4-8 mmhos	moderate	A1
8-15 mmhos	high	A2
> 15 mmhos	very high	A3

Although not entering in the main classification exercise, salinity and sodicity should be always assessed, even empirically, and influence the choice of the primary or secondary limiting factors.

(ii) <u>Where and How to Observe:</u>

Land can be classified anywhere. There may be different situations or different purposes for which a land class assessment is needed, such as:

(a) A field technician wants to start his soil conservation work, but he has no idea about the physical conditions of the land and he has no maps, aerial photos and he needs to make a plan.

In this case, the most simple and practical way to classify the land, is to make a simple sketch map of the area and delineate as accurately as possible different type of land uses and sub-units based on the major changes of slope. After these demarcations and delineations are made, technicians can make their observations at a representative point of each type of land. The **land classification can be used as part of the integrated village development planning work or any other type of grassroot level plan.**

(b) A field technician has access to maps, aerial photos and he needs to prepare a sub-watershed development plan, detailed village plans and/or other surveys related to identify constraints related to soil erosion and potentials for conservation-based development. In this case mapping would be an accurate exercise and facilitate the reconnaissance of the terrain in order to identify the spots for observing land features and classifying the land.

The land features to be observed or measured are as follows:

- The slope is measured in the landscape with the clinometer or any other field survey equipment or method.

- The past erosion, waterlogging, infiltration and stoniness (or rockiness) are assessed by observing the landscape and by using the field description guides given for these features.
- The soil depth and the texture can be observed in a gully, in a road cutting, in a pit or by augering.

4.2.4 Description of the soil conservation requirement classes

The Land Classification for use in soil conservation attempts to identify the major SOIL CONSERVATION REQUIREMENT CLASSES and THE MOST SUITABLE LAND MANAGEMENT for these classes.

As mentioned above, basically eight Soil Conservation Requirement Classes and eight groups of suitable Land Management are considered. The risk of soil erosion increases through classes I to IV and VI to VIII , as well as the requirements for soil conservation practices and management. Class V is a special case; this is a wet land, very poorly drained, it has major management problems but generally no erosion hazards.

The table given at the end of this section provides guidance on how to select the most appropriate soil conservation measures based on the limitations of each class.

CLASS I

The land classified in this class is the best for use in agriculture. Intensive cropping can be used and no soil conservation measures need to be applied other than preventive ones to maintain a good vegetative cover and increase water storage capacity and utilization.

Requirements

To be placed in this class, the following requirements have to be met:

- Slope: < 3%
- Soil depth: > 150 cm.
- No past erosion noticeable
- Texture: medium (T3 to T6)
- No waterlogging
- Good infiltration
- Stoniness: < 15%

Land class unit: I (without any limiting factor)

CLASS II

Land in this class has minor limitations for intensive cropping and requires some soil conservation practices to prevent deterioration.

The minor limitations will include one or more of the following:

- Slope: < 8 %
- Soil depth: > 100 cm
- No past erosion noticeable
- Medium and fine textures (T3 to T6), heavy clay excluded
- No waterlogging problems
- Good infiltration
- Stoniness: < 30 %

land class units:

IIL : limiting factor Slope 3-8% (L2)
IID : limiting factor Soil depth 100-150 cm (D2)
IIT : limiting factor Clay soil texture (T6)
IIS : limiting factor Stoniness 15-30% (S1)

CLASS III

Land in Class III has more restrictions to use than in Class II and when used for intensive cropping, conservation practices are usually more difficult to apply and maintain.

The limitations will include one or more of the following:

- Slope: < 15%
- Soil depth†100 cm
- Past erosion: nil to slight
- Texture: medium and fine (T3 to T7) (heavy texture included, i.e. clay soils or Vertisols)
- Waterlogging: none to intermittently
- Infiltration: none to moderate
- Stoniness: < 50%

Land class units:

IIIL : major limiting factor Slope 8-15% (L3)
IIIE : major limiting factor Slight past erosion (El)
IIIW : major limiting factor Intermittently waterlogged (W1)
III i: major limiting factor Moderate infiltration (I1)

CLASS IV

The restrictions to use this land class for agriculture are greater than those in Class III, and when used for intensive cropping the conservation practices are more difficult to apply and maintain.

The limitations will include one or more of the following:

- Slope: < 30%
- Soil depth‡50 cm
- Past erosion: nil to moderate
- Waterlogging: nil to regularly waterlogged
- Infiltration: good to poor

All soil textures (except sand) and < 50% of stones are accepted in this class.

Land class units:

IVL : major limiting factor Slope 16-30% (L4)
IVD : major limiting factor soil depth 50-100 cm (D3)
IVE : major limiting factor Moderate past erosion (E2)
IVW : major limiting factor Regularly waterlogged (W2)
IV i: major limiting factor Poor infiltration (I2)

CLASS V

Class V is allotted to land unsuitable for intensive or perennial crops by reasons other than erosion hazards. Examples include swampy areas, temporary water courses and intermittent river beds flooded every year during the rainy season. Cultivation of rice and/or other crops or temporary grazing could be possibly take place during part of the rainy season and/or the dry season. This class does not included bench terraces or overflow bunds/dams cultivated with rice or other crops.

Land class units:

VW : swampy areas, & soils always wet (W4)
VF : river beds or areas flooded every year

CLASS VI

The land has such severe limitations that annual intensive cropping should be discouraged, but it could be productive under perennial vegetation (perennial crops or grazing).

Extensive areas of this class located on steep Slopes (30-50%) are currently cultivated in Myanmar. If the soils on these steep slope have an effective depth of more than 50 cm, the development of reverse terraces or other adapted and effective physical and/or biological measures to control erosion may allow the land to be used for annual crops.

The limitations will include one or more of the following:

- If slope 15-30% the soil depth >25 cm
- If slope 30-50% the soil depth >50 cm
- Stoniness >85% (boulders included)
- Texture: all classes (except sand)
- Past erosion: nil to moderate
- Waterlogging: nil to regularly waterlogged
- Infiltration: good to poor

Land class units:

VIL : major limiting factor Slope 30-50% (L5)
VID : major limiting factor Soil depth 25-50 cm (D4)
VIS : major limiting factor Stoniness 50-85% (boulders excluded)(S3)

CLASS VII

Land which has such severe limitations as to exclude cultivation. The land is suitable for afforestation, rough grazing and wildlife. Unfortunately, many areas in the Dry Zone are found under this class and cultivated extensively for survival purposes. Their deterioration and degradation is fast and often irreversible. Some of these areas may be restored to allow cultivation of perennial crops or annuals (low demanding crops, i.e. fodder crops) through intensive and integrated rehabilitation efforts during a few years. Otherwise this land is only suitable for area closure and reforestation purposes using soil and water harvesting devices.

The limitations will include one or more of the following:

- Slope: >50%
- Soil depth: >25 cm
- Past erosion: nil to severe
- Stoniness: < 85% (boulders included)

Accepted in this class are the following ranges of characteristics:

- Texture: all classes, except sand,
- Waterlogging: nil to regularly
- Infiltration: good to poor

Land class units:

- VIIL : major limiting factor Slope > 50% (L6)
- VIID : major limiting factor Soil depth 25-50 cm (D5)
- VIIE : major limiting factor Severe past erosion (E3)

CLASS VIII

Land which has such excessive limitations that it should not be used for crops, grazing or wood production. Use is restricted to protecting the catchment, reclaiming the degraded lands caused by severe past erosion (gully control, tree planting, regeneration of grass cover, wildlife and recreation).

The limitations will include one or more of the following:

- Soil depth: <25cm
- Very severe past erosion
- Sand texture
- Stoniness or rock outcrops >85%

For other land features, the following ranges are accepted in this class:

- Slope: all classes
- Waterlogging: nil to regularly
- Infiltration: good to poor

Land class units:

VIIID : major limiting factor	Soil depth < 25 cm (D5)
VIIIE : major limiting factor	Very severe past erosion (E4)
VIIIT : major limiting factor	Sand texture (T7)
VIIIS : major limiting factor	Stoniness or rockiness > 85% (S4)

4.2.5 How to determine the soil conservation requirement classes?

To determine the Soil Conservation Requirement Classes described above, field staff have to observe the following steps:

(a) With the climatic information of the area (or from others areas with similar climatic conditions), place the land to be classified in one of the following tentative agroclimatic classification of the Myanmar Dry Zone.

GROUP A : Rainfall 400-600 mm average, with first monsoon (occasionally also second monsoon) often erratic over time and space (low one-two years out of three).

GROUP B : Rainfall 600-800 mm average, with first or second monsoon less erratic (low one year out of three).

(b) If the land is placed in group A check the annual rainfall. If it is less than 400 mm, the present LCS is not applicable.

(c) If the land is placed in group A (with more than 400 mm rainfall) or if the land is placed in group B, proceed to collect information on soils and landscape features. Then, by using the LAND CLASSIFICATION TABLE, determine the SOIL CONSERVATION REQUIREMENT CLASSES of your area.

(d) For areas benefiting from higher rainfall the LCS is still applicable but the criteria for determining the limiting factors should be revised based upon field conditions.

4.2.6 How to use the land classification table?

The LAND CLASSIFICATION TABLE presented below, is designed to enable field staff to identify the land classes in an uniform and objective way.

The procedures in using the table are:

(a) Use the data collected in the field, which has been coded on the SOILS/LANDFORM description form (see page 87)*

(b) Start at the top left hand corner of the table (SLOPE) and find the first occurrence of the slope category recorded in the field when moving from left to right. **

(c) Proceed down in the same column to the next feature, if the data recorded is within the range allowed proceed down again to the next feature. If it is not, move to the right along the line until you find the correct range. YOU CANNOT GO BACK TO THE LEFT.

(d) Work down after you have followed this procedure for all the features, until you reach the SOIL CONSERVATION REQUIREMENT CLASS at the bottom of the table.

* Note: For simplicity, the code range allowed in a column is shown: for example 1-7 means any code between 1 and 7 inclusive (i.e.: 1,2,3,4,5,6 or 7) is allowed and the user can proceed down vertically, provided the code is within the stated range.

** Note: If the column for the SLOPE is subdivided into two, you have to continue in that sub-column until you reach SOIL DEPTH.

IMPORTANT NOTE: The land classification table do not include salinity and sodicity as primary limiting factors. The problem is that salinity and sodicity may influence the choice of a class in different ways based upon the management of saline/sodic soils and corrective measures applied. However, field technicians and farmers may recognize these problems rather easily and indicate them as a limiting factor for cultivation or planting of food and fodder crops, pastures and tree species. Therefore it is recommended to insert (A) as a limiting factor whenever conditions are severely affecting the growth of plants, the stability of structures and threaten better-off fields located downstream. Sodicity would me mentioned using the symbol Sd or in a descriptive manner.

LAND CLASSIFICATION

LIMITING FACTOR	RANGE OF CODES PERMITTED IN THE COLUMN								
Slope (L)	1	2	3	4	1- 4	5	6	1- 6	1 - 6
Soil Depth (D)	1	1 -2	1 - 2	1 - 3	1 - 4	1 - 3	1 - 4	1 - 5	1 - 5
Past Erosion (E)	0	0	0 - 1	0 - 2	0 - 2		0 - 3	0 - 4	0 - 4
Waterlogging(W)	0	0	0 - 1	0 - 2	0 - 2		0 - 2	0 - 2	0 - 3
Infiltration (i)	0	0	0 - 1	0 - 2	0 - 2		0 - 2	0 - 2	0 - 2
Topsoil Texture (T)	3 - 5	3 - 6	3 - 7	2 - 7	2 - 7		2 - 7	1 - 7	1 - 7
Surface stoniness or rockinness (S)	0	0 - 1	0 - 2	0 - 2	0 - 3		0 - 3	0 - 4	0 - 4
Soil Conservation Requirement class (SCRC)	I	II	III	IV	VI		VII	VIII	V
Land use suitability	Land suitable for annual crops				Land suitable for grazing or perennial crops		Land suitable for forestry	Land not suitable for agriculture	Swampy areas, river beds...

SOILS/LANDFORM DESCRIPTION FORM

Watershed: Village: Region Altitude Rainfall	Agroclimatic Zone Present Land Use Parent Material Major Landform	No of Observation Auger Gully Road Cut Pit Observer Date	Aerial Photo No. Soil Unit Symbol L E W I S D T ...... Land Class Unit

INFORMATIONS NEEDED FOR LAND CLASSIFICATION

SLOPE (L)

0-3 %	L1	☐
3-8 %	L2	☐
8-15 %	L3	☐
15-30 %	L4	☐
30-50 %	L5	☐
> 50 %	L6	☐

SOIL DEPTH (D)

> 150 cm	D1	☐
100-150 cm	D2	☐
50-100 cm	D3	☐
25-50 cm	D4	☐
< 25 cm	D5	☐

PAST EROSION (E)

None	E0	☐
Slight	E1	☐
Moderate	E2	☐
Severe	E3	☐
Very Severe	E4	☐

TEXTURE (T)

Sand	T1	☐
Sandy loam	T2	☐
Loam	T3	☐
Silt loam	T4	☐
Clay loam	T5	☐
Silt clay, clay	T6	☐
Heavy clay	T7	☐

WATERLOGGING (W)

None	W0	☐
Intermittently waterlog.	W1	☐
Regularly waterlogged	W2	☐
Swamps	W3	☐

INFILTRATION (I)

Good	I0	☐
Moderate	I1	☐
Poor	I2	☐

STONINESS OR ROCKINESS (S)

< 15 %	S0	☐
15-30 %	S1	☐
30-50 %	S2	☐
50-90 %	S3	☐
> 90 %	S4	☐

Size .... cm.

ADDITIONAL INFORMATIONS (Optional)

pH (R)

< 5	R1	☐
5-6.5	R2	☐
6.5-7.5	R0	☐
7.5-8.5	R3	☐
> 8.5	R4	☐

SALINITY (A) (Only for dry areas)

4 mmhos	A0	☐
4-8 "	A1	☐
8-15"	A2	☐
> 15"	A3	☐

CARBONATES

Effervecence to HCL: Yes No
if yes add * to R.

DOMINANT COLOUR

Black	☐	Brown	☐	Red	☐
Yellow	☐	Grey	☐	White	☐

EXAMPLE OF HOW TO CLASSIFY THE LAND

(1)

SOILS/LANDFORMS DESCRIPTION FORM

Watershed: XY Village : Kuley Region: Kpd Altitude: 300 mml Rainfall 500-600 mm	Agroclimatic Zone Semi-arid type 4 Present Land Use Cultivated land Parent Material Sandstone Major Landform Sedimentary Plain	No of Observation 4 Auger Gully ✓ Road Cut Pit Observer UANY VOLSAN Date 13-7-98	Aerial Photo No. ✓ Soil Unit Symbol L E W I S D T ...... Land Class Unit IV DL

INFORMATIONS NEEDED FOR LAND CLASSIFICATION

SLOPE (L)
- 0-3 % L1 [ ]
- 3-8 % L2 [ ]
- 8-15 % L3 [X]
- 15-30 % L4 [ ]
- 30-50 % L5 [ ]
- > 50 % L6 [ ]

SOIL DEPTH (D)
- > 150 cm D1 [ ]
- 100-150 cm D2 [ ]
- 50-100 cm D3 [X]
- 25-50 cm D4 [ ]
- < 25 cm D5 [ ]

PAST EROSION (E)
- None E0 [ ]
- Slight E1 [ ]
- Moderate E2 [X]
- Severe E3 [ ]
- Very Severe E4 [ ]

TEXTURE (T)
- Sand T1 [ ]
- Sandy loam T2 [ ]
- Loam T3 [ ]
- Silt loam T4 [X]
- Clay loam T5 [ ]
- Silt clay, clay T6 [ ]
- Heavy clay T7 [ ]

WATERLOGGING (W)
- None W0 [X]
- Intermittently waterlog. W1 [ ]
- Regularly waterlogged W2 [ ]
- Swamps W3 [ ]

INFILTRATION (I)
- Good I0 [ ]
- Moderate I1 [X]
- Poor I2 [ ]

STONINESS OR ROCKINESS (S)
- < 15 % S0 [X]
- 15-30 % S1 [ ]
- 30-50 % S2 [ ]
- 50-90 % S3 [ ]
- > 90 % S4 [ ]

Size .... cm.

ADDITIONAL INFORMATIONS (Optional)

pH (R)
- < 5 R1 [ ]
- 5-6.5 R2 [ ]
- 6.5-7.5 R0 [X]
- 7.5-8.5 R3 [ ]
- > 8.5 R4 [ ]

SALINITY (A) (Only for dry areas)
- 4 mmhos A0 [ ]
- 4-8 " A1 [X]
- 8-15" A2 [ ]
- > 15" A3 [ ]

CARBONATES

Effervecence to HCL: Yes (No)
if yes add * to R.

DOMINANT COLOUR

Black [ ] Brown [X] Red [ ]
Yellow [ ] Grey [ ] White [ ]

LIMITING FACTOR	RANGE OF CODES PERMITTED IN THE COLUMN								
Slope (L)	1	2	(3)	4	1-4	5	6	1-6	1-6
Soil Depth (D)	1	1-2	1-2	(1-3)	1-4	1-3	1-4	1-5	1-5
Past Erosion (E)	0	0	0-1	(0-2)	0-2		0-3	0-4	0-4
Waterlogging (W)	0	0	0-1	(0-2)	0-2		0-2	0-2	0-3
Infiltration (i)	0	0	0-1	(0-2)	0-2		0-2	0-2	0-2
Topsoil Texture (T)	3-5	3-6	3-7	(2-7)	2-7		2-7	1-7	1-7
Surface stoniness or rockinness (S)	0	0-1	0-2	(0-2)	0-3		0-3	0-4	0-4
Soil Conservation Requirement class (SCRC)	I	II	III	(IV)	VI		VII	VIII	V
Land use suitability	Land suitable for annual crops				Land suitable for grazing or perennial crops		Land suitable for forestry	Land not suitable for agriculture	Swampy areas, river beds...

(2)

SOILS/LANDFORMS DESCRIPTION FORM

Watershed: Village: Kambarle Region: Kpol Altitude: 600 masl Rainfall: 500 mm	Agroclimatic Zone: Semi-arid Present Land Use: GRAZING LAND Parent Material: Volcanic Rocks Major Landform: Hillside	No of Observation: 2 Auger Gully ✓ Road Cut Pit Observer: UNAY VOLSAN Date: 15-7-98	Aerial Photo No. ✓ Soil Unit Symbol: LEWIS D T ...... Land Class Unit: VII ED

INFORMATIONS NEEDED FOR LAND CLASSIFICATION

SLOPE (L)
- 0-3 % L1 ☐
- 3-8 % L2 ☐
- 8-15 % L3 ☐
- 15-30 % L4 ☒
- 30-50 % L5 ☐
- > 50 % L6 ☐

SOIL DEPTH (D)
- > 150 cm D1 ☐
- 100-150 cm D2 ☐
- 50-100 cm D3 ☐
- 25-50 cm D4 ☒
- < 25 cm D5 ☐

PAST EROSION (E)
- None E0 ☐
- Slight E1 ☐
- Moderate E2 ☐
- Severe E3 ☒
- Very Severe E4 ☐

TEXTURE (T)
- Sand T1 ☐
- Sandy loam T2 ☐
- Loam T3 ☐
- Silt loam T4 ☒
- Clay loam T5 ☐
- Silt clay, clay T6 ☐
- Heavy clay T7 ☐

WATERLOGGING (W)
- None W0 ☒
- Intermittently waterlog. W1 ☐
- Regularly waterlogged W2 ☐
- Swamps W3 ☐

INFILTRATION (I)
- Good I0 ☐
- Moderate I1 ☐
- Poor I2 ☒

STONINESS OR ROCKINESS (S)
- < 15 % S0 ☐
- 15-30 % S1 ☒
- 30-50 % S2 ☐
- 50-90 % S3 ☐
- > 90 % S4 ☐

Size 10-15 ......

ADDITIONAL INFORMATIONS (Optional)

pH (R)
- < 5 R1 ☐
- 5-6.5 R2 ☐
- 6.5-7.5 R0 ☐
- 7.5-8.5 R3 ☒
- > 8.5 R4 ☐

SALINITY (A) (Only for dry areas)
- 4 mmhos A0 ☐
- 4-8 " A1 ☒
- 8-15" A2 ☐
- > 15" A3 ☐

CARBONATES

Effervecence to HCL: Yes (No)

If yes add * to R.

DOMINANT COLOUR

Black ☐ Brown ☐ Red ☐

Yellow ☒ Grey ☒ White ☐

LIMITING FACTOR	RANGE OF CODES PERMITTED IN THE COLUMN								
Slope (L)	1	2	3	(4)	1-4	5	6	1-6	1-6
Soil Depth (D)	1	1-2	1-2	1-3	(1-4)	1-3	1-4	1-5	1-5
Past Erosion (E)	0	0	0-1	0-2	0-2		(0-3)	0-4	0-4
Waterlogging (W)	0	0	0-1	0-2	0-2		(0-2)	0-2	0-3
Infiltration (i)	0	0	0-1	0-2	0-2		(0-2)	0-2	0-2
Topsoil Texture (T)	3-5	3-6	3-7	2-7	2-7		(2-7)	1-7	1-7
Surface stoniness or rockinness (S)	0	0-1	0-2	0-2	0-3		(0-3)	0-4	0-4
Soil Conservation Requirement class (SCRC)	I	II	III	IV	VI		(VII)	VIII	V
Land use suitability	Land suitable for annual crops				Land suitable for grazing or perennial crops		Land suitable for forestry	Land not suitable for agriculture	Swampy areas, river beds...

4.2.7 *How to determine the limiting factor(s)?*

One or a maximum of two limiting factors should be recorded and noted following the land class. The limiting factors are: SLOPE, SOIL DEPTH, PAST EROSION, TEXTURE, WATERLOGGING, INFILTRATION AND STONINESS OR ROCKINESS. Other factors that may be included are SOIL REACTION and SALINITY or SODICITY.

The worst condition of each limiting factor is located successively to the right of the Land Classification Table. So the feature with an observed range located AT THE MOST RIGHT of this table is the MAJOR LIMITING FACTOR.

› If all limiting factors are in the same column of the table, the major limiting factor is the first in the column (slope). A second limiting factor may be identified among the other land features if it is considered to be important in the future management or conservation aspects of the land.

THE MAJOR LIMITING FACTOR IS THE ONE THAT DETERMINES THE LAND CLASS UNIT.

The SYMBOLS OF THE LAND CLASS UNITS consist of:

Soil conservation requirement class symbol and limiting factor symbols as follows:

Soil conservation requirement class symbols: I, II, III, IV, V, VI, VII, VIII

Limiting factors symbols: Slope : L, Soil depth: D, Past erosion: E, Waterlogging: W, Infiltration: I, Texture: T, Stoniness or rockiness: S, Soil reaction (pH): R, Salinity/ Sodicity*: A or Sd.

Examples of Land Class Units (LCU) symbols: IIL, IIIL, IVD, VIIE, VIITA, VIILD, VW, VIIIE

4.2.8 *Selection of soil and water conservation measures for each land class unit*

Knowing the SOIL CONSERVATION REQUIREMENT CLASS and the LAND CLASS UNIT, the technicians can select the most appropriate soil conservation measure for each particular land class unit.

To be realistic in the selection of the soil conservation measures the present Land Use should be considered. In the following pages an example on how to develop soil conservation packages for each land class unit is provided.

Procedure for identification and selection of soil and water conservation measures:

1. Check present land use.
2. Undertake land classification exercise and determine land class unit (soil conservation requirement class + limiting factors).
3. Check land class unit against present land use assessed above.

(*) In absence of soil laboratory analysis assess the salinity or sodicity based on your observations. If you consider them as a problem just put the symbol of the limiting factor A for saline and Sd for sodic conditions.

4. Select one or more soil and water conservation measures seemingly appropriate within existing conditions.
5. Submit to farmers the list of measures, their description and implications on the farming system (advantages and limitations).
6. Negotiate testing and demonstration if necessary and make the required arrangements for awareness, training, group formation, testing, implementation, integration and monitoring & evaluation, inputs requirements and their utilization, contracts, schedule and mode of intervention.

› The table given at the end of this section include indicative and general recommendations about the different SWC measures to apply.

› For detail description of these measures refer to part 5 of the guideline. It should be noted that in most cases recommendations about changes in land use (for instance from cultivated to forested land) are of difficult if not impossible implementation in practice. This happen often in classes VI and VII (sometimes also VIII) which are not suitable for cultivation but are often extensively used for cropping by villagers, particularly by poor farmers. Technicians would then find extremely difficult to suggest those farmers changing the land use because those lands are their only means for survival. In this case the focus should be on selecting SWC measures which will reduce soil loss and degradation as much as possible within the set of constraints found in those lands.

› For example, a land classified as VIIDI (shallow depth, poor infiltration, likely crusts, poor water holding capacity) should normally be converted into a forest land or an area closure under intense care and regeneration. However, if the farmer wants to keep such an area under cultivation, a possible package may be: i) contour bunds which will retain moisture longer and control soil erosion, ii) ripping (2-3' depth) which would break hard pans, iii) ley pasture which would improve fertility and water retention (sowing of legumes along the ripped areas) and, once cropped, iv) the use of sound rotations, intercropping, mulching of residues, contour ploughing and application of sufficient FYM which would allow the cultivation of these areas in a sustainable way.

Although not optimal, **selection of SWC should be realistic and likely to be adopted by land users.** However, there are cases where changes in land use can occur and seen as advantageous by farmers, particularly if an entire package of measures is applied and the expected benefits are considered by land users attractive and of low risk. For example, a marginal land more or less abandoned or left fallow (class VI-VII) for years may be rehabilitated effectively if fast growing legume trees/shrubs are planted in rows along bunds or rainfall multiplier systems and improved legumes & grass pasture species are sown in between. After 3-5 years, the biomass (woody and vegetative) produced by the area would certainly capture land users interest towards keeping vegetation along the bunds (although pollarded or side pruned regularly to avoid shading and competition with crops) and use a better rotation system for crop production or improve fallow.

⇒ **There is ample scope to upgrade land class units through patient and integrated soil and water conservation packages and therefore land class units should never be seen as a rigid and irreversible classification but rather as a starting point or benchmark from where improvements have to be made to make things changing for the better.**

Currently, although several SWC packages introduced by the project seem promising and welcome by land users, additional information on their performance and impact is required. This applies to the monitoring of fertility levels, soil loss, yields, rate of adoption and dissemination and technology change and improvement. It is an on-going process which take several years and often never lasts. In this respect, the various **SWC recommendations given in this document should be considered only indicative and of inspiration for finding area specific solutions to the land properly tailored around people's needs.**

In the coming years, for each major agroclimatic and socio-economic sub-unit found in the Dry Zone (by cluster, territorial units or homogeneous blocks having similar cropping systems, socio-economic conditions, culture, soils and landscape features), it is recommended that field staff should develop and refine area-based land classification systems where f**or each land class unit and present land use a range of most appropriate soil and water conservation measures would be identified based upon tangible field results.**

In other words, field staff working in a given area will gradually refine and develop SWC technical packages that will be suitable for each land use according to its capability based upon local conditions and farming systems.

At the end of this section an example is given for three major land uses. As mentioned above, the list of Soil and Water Conservation Options is over-simplified and not exhaustive, and should be elaborated or modified, according to the experience gained by the field technicians working in different areas of the Dry Zone.

How to use the land classification table for use in soil and water conservation?

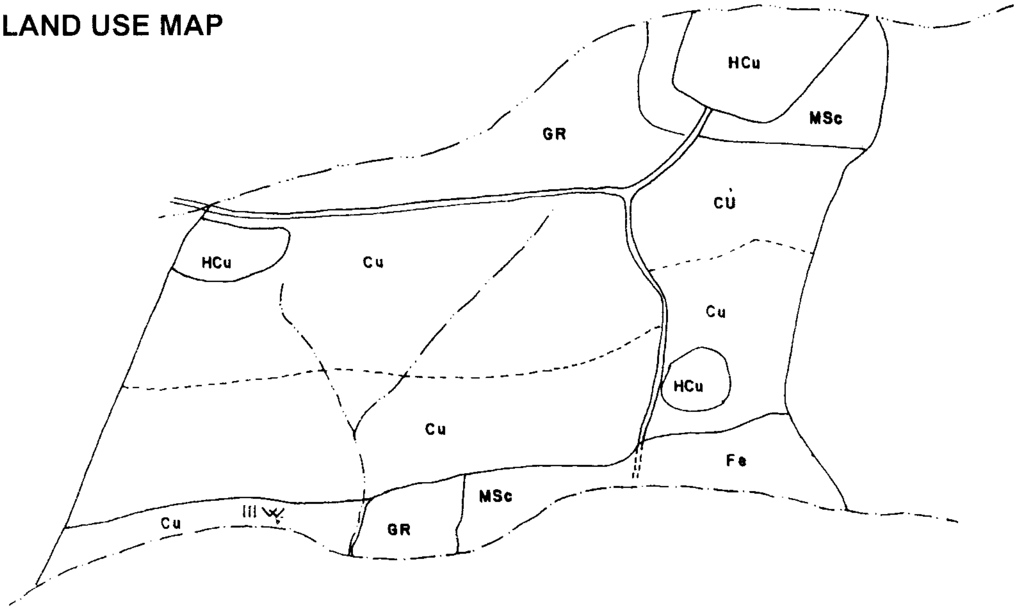
1. In the list of Land Class Units located on the left side of the table, find the LCU that you have assessed. The land class units listed in the table include those units with a primary limiting factors. Secondary limiting factors will be inserted at your discretion based upon local conditions.
2. All possible Land Class Units are listed, if you do not find your land class unit, something is wrong, check again with your Land Classification Table until you find the correct Land Class Unit.
3. Proceed on the right side of the table and select the group of options in the appropriate column among the three major land utilisation types (cultivated land, grazing land and forest land).
4. From the list of options, select the most appropriate soil and water conservation measure (s) together with land users. Options are selected not only based upon primary limiting factors but also on secondary limiting factors considered of relevance for design, implementation and performance of measures.

4.2.9 Prepare a land use and land classification map of your area

The preparation of accurate Land use/Base maps and Land Classification maps is an integral part of the planning work for soil and water conservation. A description on how to draw a map is given in the Village Planning Methodology field document. Estimate the area (ha/acres) for each land use type and its land class unit.

Example of Land Use maps, Land Classification map and Development map

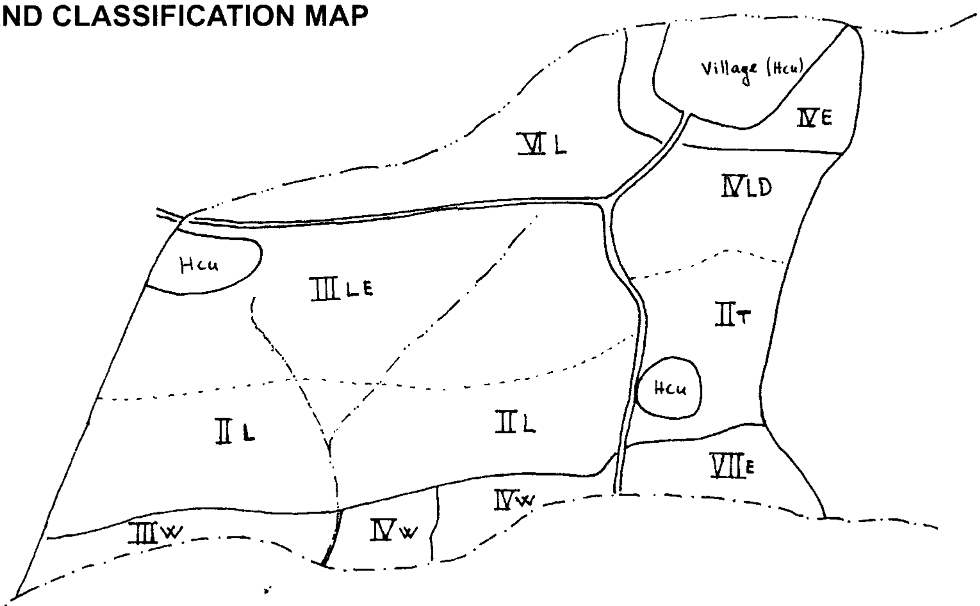
(1) LAND USE MAP



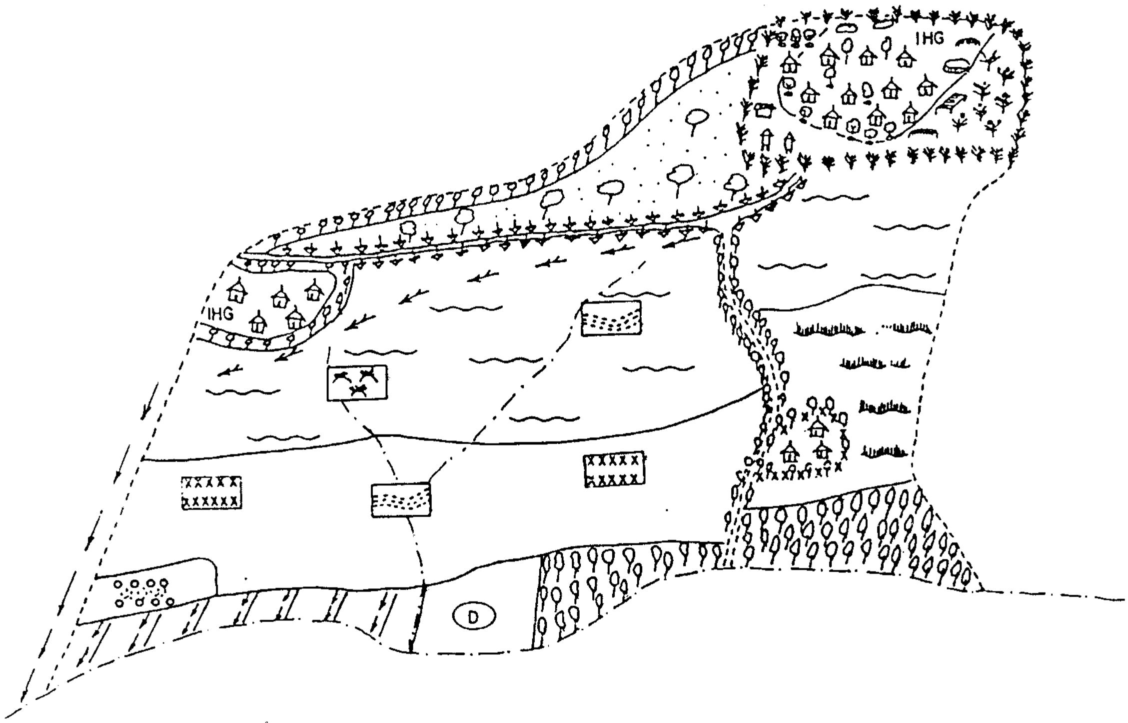
LEGEND

- RIVER
- SEASONAL RIVER
- SUB WATERSHED BOUNDARY
- COMMUNITY BOUNDARY
- FEEDER ROAD
- LAND USE SUB UNITS
- Cu — CULTIVATED LAND
- GR — GRAZING LAND
- MSc — MISCELLANEOUS LAND
- Fe — FOREST AREA
- HCu — HOMESTEADS / VILLAGE

(2) LAND CLASSIFICATION MAP



(3) DEVELOPMENT PLAN MAP



LEGEND

- SOIL BUNDS
- GRASS STRIPS
- ALLEY CROPPING
- STRIP CROPPING
- CONTOUR CROPPING
- LEY CROPPING
- CUTOFF DRAIN
- WATERWAY
- WOODLOT PLANTATION
- BORDERLINE TREE PLANTATION
- FIBRE TREES
- FRUIT TREES
- HOME SHADE TREES
- LIVE FENCE
- COMPOST PREPARATION
- NURSERY
- IMPROVED HOMEGARDEN — IHG
- SILVIPASTURE SITE
- BROAD BED & FURROW PLOWING SYSTEM
- DRAINAGE IMPROVEMENT — D

THE LAND CLASSIFICATION TABLE FOR USE IN SOIL AND WATER CONSERVATION

LAND CLASS UNIT	MAJOR LIMITING FACTOR	CULTIVATED LAND (Cu)	GRAZING LAND (Gr)	FOREST LAND (Fe)
I	Nil	- Intensive cropping (high yielding varieties, pest management, improved rotation + maintain good vegetation cover +/- grass/paved waterways if necessary to improve drainage. - Explore potential for irrigation.	1. Convert to cultivated land (+ options class I) 2. Grassland improvement/paddock systems/improved pastures/optimal grazing for intensive grassland management 3. Intense cultivation of forage crops.	1. Convert to cultivated land (+ options class I) 2. Convert into agro-forestry site or horticulture site 3. Multi-layer gardening 4. Maintain natural forest (if exists) and enrich tree plantation
II L	Slope 2-8%	1. Contour cropping 2. Strip and intercropping 3. Grass strips (if applicable) 4. Boundary level bunds +/- spillways 5. Contour/border bunds widely spaced +/- spillways (stone or soil/grassed) 6. Alley cropping + cutoff drain above fields if necessary + stabilized waterway 7. Mulching residues/manuring/composting + contour ploughing, improved rotation, etc.	Same as above + select options in class II Cu	Same as above + select options in class II Cu
II S	Stoniness 15 - 30%	removal of stones + apply options of class I	Same as above	Same as above
II D	Soil depth 100-150 cm	1. Improve root development (organic farming, deep plowing, etc.) + Apply options for Class II L	Same as above	Same as above
II T	Texture clay loam/silt clay	2. Application of compost + agronomic measures able to improve soil structure (ley cropping, intecropping, improved rotations, mulching, green manure, etc.) + Apply options of Class II L	Same as above + If converted to cultivated land apply option for present class	Same as above + If converted to cultivated land apply option for present class

LAND CLASS UNIT	MAJOR LIMITING FACTOR	CULTIVATED LAND (Cu)	GRAZING LAND (Gr)	FOREST LAND (Fe)
III L	Slope 8-15%	1. Contour soil bunds +/- spillways. 2. Boundary/corner bunds+/- spillways based upon conditions. Reinforce bunds in slight depressions with stone riser /key. 3. Stone bunds and stone faced soil bunds+/- spillways. 4. Combination of bunds + grass strips (if applicable+ bund stabilization + 4. Cutoff drain above fields if necessary + stabilized waterway, mulching reidues/manuring/composting	1. Convert to cultivated land + apply measures for III L Cu. 2. Grassland improvement (contour bunds + sowing of improved grass & legume) 3. Ley pasture 4. Convert to an agrosilvipasture site + cutoff drain above fields if necessary + stabilized waterway	Sames as above + strip plantation of trees along contours using improved pits or trenches/microbasins
III E	Slight past erosion	1. Cutoff drain above fields if necessary + stabilized waterway + 2. If slope 2-8% aply also options of class II L 3. If slope < 3% apply leveling and bench terrace construction + checkdam spillway	Same as above + control carrying capacity of grassland (control grazing, rotational grazing, tethering, etc.)	1. Same as for class I + cutoff drain + encourage grass cover (control grazing)+ plant N-fixing trees + 2. If slope 2-8% apply herring bones (<5%), trenches or improved pits for tree planting.
III W	Intermittently waterlogging	1. Drainage improvement (drains 0,5% slope) + waterway (stabilized with waterlogged resistant species) 2. Broad bed and furrow system +ripping of hard pans 3. If slope 2-8% apply also options of class II L + spillways on all type of bunds + select waterlogging resistant crops, particularly along bunds and boundaries.	1. Convert to cultivated land + apply options III W 2. Grass land improvement (same as above + waterlogging resistant species) 3. Convert to agrosilvipasture site	Same as options for class II + plant trees waterlogging resistant and/or trees reclaiming waterlogged areas Note: trenches with high/larger tie +mulching herring bones with large tie (1')+mulching microbasins planted only second year after first year mulching
III S	Stoniness 30-50%	Removal of stones + if slope 2-8% also apply the optinons of class IIL Note: physical structures made or reinforced by stones	Same as above based on secondary limiting factors + removal of stones Note: physical structures made or reinforced by stones	1. Same as options for class I. + If slopes 2-8% apply structures reinforced with stones and plant trees along contours (along stone bunds, stone reinforced trenches)

LAND CLASS UNIT	MAJOR LIMITING FACTOR	CULTIVATED LAND (Cu)	GRAZING LAND (Gr)	FOREST LAND (Fe)
IV L	Slope 15-30%	1. Contour soil bunds at closer interval (Vert. Int. 1-1.2 meters) + strong double sized stone riser to reinforce bunds in slight depressions or stone key. Corner bunds by stones + key + provision of stone spillway and apron 2. Stone faced soil bunds (both sides) + spillway 3. Stone bunds + collection ditch - spillway (if necessary) · bund stabilization with grasses/shrubs · Mulching, compost application, contour ploughing, boundary planting 4. Bench terraces + above mgt. Options	1. Convert to cultivated land + apply measures for III L Cu 2. Grassland improvement + stone lines/soil bunds 1 m VI + apply measures for IIIL Gr 3. Convert to an agrosilvipasture site – • cutoff drain above fields if necessary + stabilized waterway (stones) + control grazing	Same as above + Only trenches and microbasins (if stones available) for physical structures Note: great care on layout and dimensions
IV E	Moderate past erosion	1. cutoff drain above fields if necessary + stabilized waterway – If slope 2-8% apply also options of class II L (if slope < 3% apply leveling + bench terrace construction + spillway checkdam) If slope 8-15% apply also options of class III L	Same as above + control grazing + checkdams/brushwood	Same as above + Checkdams/brushwood
IV D	Soil depth 50-100 cm	1. Select crops with shallow rooting system If slope 2-8% apply also options of class II L + If slope 8-15% apply also options of class III L 2. Ripping and ley cropping along ripped areas + above options	Same as above + ripping	Same as options for class IIIE + herring bones or microbasins (if stones available) for tree planting. Trenched only in sandstones (using crow bars)

LAND CLASS UNIT	MAJOR LIMITING FACTOR	CULTIVATED LAND (Cu)	GRAZING LAND (Gr)	FOREST LAND (Fe)
IV W	Regularly waterlogged	1. Selective seasonal cropping 2. Drainage improvement + 3. Bed and furrow system + waterways If slope 2-8% apply also options of IIIW (graded structures - 0.5% max.) If slope 8-15% ripping + ley cropping + graded structure + stabilization with waterlogging resistant species. Note: Check if there are sodicity problems which relate to waterlogging & infiltration problems and apply appropriate changes on design of structures and selection of plant species	1. Convert to cultivated land + apply measures for II I Cu if slopes 2-8% 2. Grassland improvement + graded stone lines/soil bunds 1 m VI 3. Convert to an agrosilvipasture site + drainage improvement Note: Check if there are sodicity problems which relate to waterlogging & infiltration problems and apply appropriate changes on design of structures and selection of plant species	1. Convert to cultivated land + apply options for IV W 2. Convert into agroforestry site + selection of waterlogging resistant species Note: Check if there are sodicity problems which relate to waterlogging & infiltration problems and apply appropriate changes on design of structures and selection of plant species
IV i	Poor infiltration	1. Deep ploughing + ripping + ley cropping 2. Soil structure improvement (mulching, composting, manuring) If slope 2-8% apply also options of class II I. + If slope 8-15% apply also options of class III L and III W Note: Check if there are sodicity problems which relate to infiltration problems and apply appropriate changes on design of structures and selection of plant species	1. Convert to cultivated land + apply option for IVi + 2. Control grazing (seasonal only) 3. Convert to an agrosilvipasture site with trees N-fixing, deep rooting system, high litter producing species + grass and legumes with strong tap roots + ripping Note: Check if there are sodicity problems which relate to infiltration problems and apply appropriate changes on design of structures and selection of plant species	1. Convert to cultivated land + apply options for IV i 2. Convert to fuelwood plantation with trees having high penetration capacity 3. Trees planted in microbasins or herring bones after heavy mulching (2^{nd} year planting) + compost into larger pits within structures 4. Trenches with high large ties + large pits + compost (plantation 1^{st} year) + mulching 5. Encourage grass cover + control grazing most part of the year or cut and carry Note: Check if there are sodicity problems which relate to infiltration problems and apply appropriate changes on design of structures and selection of plant species

LAND CLASS UNIT	MAJOR LIMITING FACTOR	CULTIVATED LAND (Cu)	GRAZING LAND (Gr)	FOREST LAND (Fe)
V	Swamps river beds	1. Not applicable except perhaps during short periods of the year for rice of waterlogging tolerant crops. Need reclamation (drainage network, outlet construction, etc.) 2. If reclamation takes place apply options from one of the classes above based on the results from reclamation. 3. Change to acquaculture	1. Temporary grazing 2. After reclamation (drainge improvement) and eventual correction of soils suitable for intensive grass land improvement or cropping (based upon reclamation results apply options from one of the classes above). 3. Acquaculture	1. Reclamation using waterlogging resistant species starting from hedge of waterlogged areas. 2. After reclamation (drainage improvement) convert to Cu or Gr and apply options based on the class you are in depending on the results from reclamaion. 3. Encourage wildlife
VI L	Slope 30 -50%	1. Establish perennial crops + contour planting on contour terraces 2. Stone bunds (if stones available) 3. Convert to grassland or forest land 4. Bench terraces for annual crops + cutoff drain above fields if necessary + stabilized waterway + apply soil management and agronomic Measures as class IVL	4. Grassland improvement + stone bunds 1 m vert interval 5. Grassland improvement + stone lines narrow spacing (10') + control grazing (limited number of animals and short periods) 3. Convert to silvipasture site + stone bunds + cutoff drain above fields if necessary + stabilized waterway	1. Establish silvipasture site + stone bunds or hillside terraces for tree planting 2. Enriching plantation + trenches + microbasins (if stones available) 3. Fuelwood plantation + trenches/ microbasins 4. Tree planting in contour hillside terraces (backslope or level) 5. Tree planting in double slope hillside terraces
VI D	Soil depth 25-50 cm	1. Convert to grassland or forest land 2. Establish perennial/annual crops with Shallow rooting system + ripping if slope< 8 -15% 3. If slope 2-30% the perennia./annual crops should be along contours and supplemented by contour bunds (reinforced) at different Vert. Int. based on slopes	1. Grassland improvement (options IV D) + bunds at closer interval + ripping if slope< 15% + ley pasture and mulching 2. Grassland improvement + stone lines + control grazing 3. convert to silvipasture site	1. Establish silvipasture site (along contours) + structures (tree N-fixing and strond tap roots). 2. Enriching plantation + Microbasins (if stones available) or herring bones/half-moon structures if slopes < 5% 3. Tree planting/fuelwood woodlot plantation+ trenches if slopes 5-30% 4. Tree planting/fuelwood woodlot plantation+ microbasins if slopes 5-30% (if stones available) Tree planting/fuelwood woodlot plantation+ hillside terraces if slopes 15-30%

LAND CLASS UNIT	MAJOR LIMITING FACTOR	CULTIVATED LAND (Cu)	GRAZING LAND (Gr)	FOREST LAND (Fe)
VI S	Stoniness 50-85%	1. Removal of stones 2. Establish perennial crops 3. Convert to grassland or forest land + If slope 8-15% apply stone bunds If slope 15-30% stone bench terraces for annual crops	Same as above sections + removal of stones	Same as above + Stone microbasins Stone hillside terraces
VII L	Slope > 50%	1. Convert to forest land 2. Convert to silvipasture land Hillside terraces for annual/perennial crops + cutoff drain – stone checked waterway + Gully control if necessary	1. Convert to forest land 2. Convert to silvipasture site using hillside terraces + control grazing (cut and carry only) + cutoff drain above fields if necessary – stabilized waterway 3. Stone percolation bunds (< 75% slope) at close interval + grasses & legumes in dense rows	1. Plantation for catchment protection + trenches + Microbasins (if stones available) 2. Tree planting in microbasins 3. Tree planting in contour hillside terraces (backslope or level) 4. Tree planting in double slope hillside terraces
VII D	Soil depth > 25 cm and < 50 cm	Same as above + 1. Use shallow rooting plants – ripping if slope < 15% + soil management practices (class IVD options intensified) 2. If slopes 15-50% apply options of class VIIL 3. Convert to tree planting and grass&legumes (agrosilvipasture site) in dense rows along hillside terraces	1. Area Closure + tree planting + grass &legume row planting along structures (hillsides, stone bunds, trenches, microbasins) 2. Cut and carry system + Gully control and cutoff drain if necessary	1. Area closure + tree planting + microbasins + trenches (sandstone) 2. Area closure + tree planting using one or more of the above (excluding trenches and hillside terraces) on other soils.
VII E	Severe past erosion	1. Area closure + cut and carry 2. Convert to forest land + gully control (check dams and SS dams if possible) + cutoff drain if necessary	1. Area Closure 2. Convert to forest land (catchment protection) + gully control (ckeckdams and SS dams if possible)+ cutoff drain if necessary	1. Protection of natural species if exist 2. Area closure + gully control (checkdam) + cutoff drain if necessary 3. Encourage wildlife

LAND CLASS UNIT	MAJOR LIMITING FACTOR	CULTIVATED LAND (Cu)	GRAZING LAND (Gr)	FOREST LAND (Fe)
VIII D	Soil depth < 25 cm	1. Area closure + cut and carry Convert to forest land (catchment protection) 2. If slope < 50 % apply VIID options	1. Area Closure + cut and carry Convert to forest land (catchment protection) 2. Same as VIID	Same as above
VIII E	Very severe past erosion	1. Area closure + cut and carry Convert to forest land (catchment protection) + gully control (checkdams and SS dams if possible)	1. Area closure + cut and carry 2. Convert to forest land (catchment Protection) + gully control + enrich with grass & legumes	1. Area closure + cut and carry + cut and carry + enrich with grass & legumes 2. Encourage wildlife and natural tree regeneration
VIII T	Sand texture	Not applicable or select option for VIIIT Gr or Fe	1. Area closure + Wind erosion control	Area closure + tree planting using half moon structures + windbreaks
VIII S	Stoniness > 85%	1. Area closure + tree planting (spot planting)	1. Area closure + cut and carry	1. Catchment protection/area closure + wildlife

NOTE: The above options should be checked against the soil type conditios. If pH, salinity and sodicity are a majoror secondary limiting factor they are directly influencing the structure of the soil and thus its permeability, infiltration and stability against erosion agents. Physical structures would have to be designed differently and the range of options would considerably decrease, even on gentle slopes. The same would occur on the type and number of crops, grasses & legumes and tree species which would grow under such condition. Therefore, these factors should be carefully identified and placed directly after one of the land class units likely to indicate their occurrence such as Classes IVi and IVW, VID and all class VII and VIII.

PART IV : SOCIAL ELEMENTS, PARTICIPATORY PLANNING AND SUSTAINABILITY ISSUES

People's participation in soil and water conservation, Kuley village - Kyaukpadaung

"Listen and watch, walk and touch, be wise with your talk and experience a lot" (Roman proverb - 150 years B.C.)

1. PEOPLE'S PARTICIPATION

1.1 Introduction

"Rural people are the ultimate deciders of what will happen on the surface of the land each day. Extension services can try to influence them; market prices can try to attract them; laws can try to inhibit them or to force them; but if the farm families decide that, even under some or all of these pressures, what government or any other organization recommends is not in their own interest, they are very unlikely to change patterns of action that have - at the very least - kept them alive till today" (T.F. Shaxon, 1992).

In other words, if conservation measures are not seen beneficial by land users, even in the short term, they are unlikely to be adopted.

- New thinking in conservation put the land users first rather than the technical aspects. The latter are certainly very important but they intervene only after the identification and ranking of constraints affecting rural people. This can take place through a participatory process, involving land users right from the beginning of any endeavor attempting to conserve soils and ensure sustainable land use. It means initiating a planning approach tailored around what land users need rather than around what technicians think is best for the peasantry.
- Despite of decades of efforts undertaken in many countries, top-down recommendations for soil and water conservation were largely unwelcome and have been rarely adopted by land users as part of their land management practices. In many instances such measures were resolutely rejected because they were not considering the farming background and were not addressing farmers pressing needs.
- Participation of land users in conservation should then take place naturally and effectively by identifying their problems, appraising socio-economic conditions, exploring the potentials for improving land use and management, discussing options for implementation and testing out improved technologies at small scale first if necessary. Subsequently, only after confidence and mutual trust is being created, a wider adoption of improved conservation packages can take place.

How to achieve participatory soil and water conservation? In the last decade or so, a number of approaches have been developed and implemented to enhance people s participation in rural development in many parts of the world. Some of this approaches require multidisciplinary teams of experts and a rather high degree of coordination, a thing that government institutions of most developing countries cannot afford. Others are oversimplified and sectoral, thus not very effective to address farmers problems. A compromise should be found between the degree of accuracy needed to prepare a good conservation plan and the skills available in the field. The village level planning methodology, integrated with concepts for strategic planning and implementation such as the Elementary or Primary Territorial Units (UTEs page 110) promoted by project MYA/99/006 try to address these concerns.

1.2 Key Elements for an Effective Participatory Planning for Soil and Water Conservation

Three main elements or considerations for participatory planning for soil and water conservation are summarized as follows:

- A good participatory planning approach should be of practical use and simple.
- It should be as much multidisciplinary and comprehensive as possible in order to provide sufficient information that would enable both field staff and land users to design and implement appropriate conservation-based development measures.
- It should be realistic and based upon existing constraints and skills. Accordingly, participatory planning for SWC should aim at providing a solution, hopefully irreversible, to the problem of land degradation and food insecurity affecting a given area.

Ultimately, the proposed village planning approach (see Working Document No 1 - MYA/ 99/006) itself is nothing more than a tool meant to encourage participation and stimulate the identification of solutions to common and individual problems.

A planning exercise should not be thought by both land users and technical staff as the answer for every problem found in the field. Normally only few problems may be addressed, most likely some of those related to agriculture production and soil conservation. The rest of the problems are likely to remain beyond field technicians capacity to solve because of existing constraints such as limited knowledge, financial support and mandate.

These limitations should be made very clear to the villagers from the very beginning of any participatory effort regarding planning and implementation of conservation-based activities. Nevertheless, field staff can also play a catalyst role by forwarding to other relevant institutions (Health, Education, Infrastructure, Administration, etc.) documented information about the remaining problems, and thus may help the community to solve them in an indirect way.

The Village Level Planning methodology and formats are explained in the MYA/96/006 field document No 1. The linkages between this planning approach and the UTEs mentioned above provide the basis for further improvement of the proposed methodology and its insertion within a wider context of planning the rehabilitation and development of drylands.

The section below briefly outlines the main components of a participatory planning approach and their importance for soil and water conservation.

2. PARTICIPATORY PLANNING FOR DRY LANDS DEVELOPMENT

2.1 Nature and Scope

2.1.1 What is planning?

- A plan is a formulated or organized method by which something is to be done (concise Oxford dictionary).
- Planning is understood to be a tool for field staff to organize their work on a consultative basis with farmers to reach at the soil conservation and sustainable development objectives.

- It should be emphasized that planning not only includes a set of quantitative targets, but also an outline of OBJECTIVES.

2.1.2 Why participatory planning is needed?

- To make farmers aware about their problems and possibilities/opportunities how to solve them or contribute to their solution.
- To identify the priorities and define targets for reaching the objectives of soil conservation/ agriculture development.
- To identify, discuss and finally select an appropriate range of soil conservation-based development measures, which address the most important problems that farmers have, as presented in the problem identification/socio-economic analysis.
- To determine the overall resources requirements for the implementation of development plans.
- To minimize the risk of unacceptance or failure of the introduced soil conservation-based development measures.
- To strengthen the relationship between the extension agent/local expert and the rural community.
- To provide the necessary technical, social and managerial benchmarks for the monitoring of soil conservation-based development activities (quantitative and qualitative achievements, appropriateness of measures and farmers acceptance, timeliness and sufficient supply of inputs etc.).
- To provide a means for evaluating the effects and impact of activities.

2.1.3 What should be considered in a plan?

The following elements of planning should be considered:

(a) **Physical conditions:** topography, present land use, soils, climate, natural vegetation, water resources etc.

(b) **Socio-economic conditions:** population, traditional/local institutions, service cooperatives (if any), manpower, land tenure system, social status, gender, farming systems, food security, farmer s problems and needs, and their perception of soil erosion/ land degradation/environmental protection.

(c) **Material resources:** equipment, tools, seeds, etc.

(d) **Financial resources:** local inputs, Government inputs and external inputs (when available).

(e) **Manpower and skills** (adequate number of experts and extension agents, sufficient training and references able to guide and support field staff decisions on what, where and how activities should be selected and implemented).

2.1.4 Conservation based planning

It should be understood that, if properly carried out, most of the development activities undertaken at village level, from water development and school construction to improved agronomic practices and provision of agricultural inputs would have a positive implication as far as conservation is concerned. That is why we suggest defining rural development activities as soil and water conservation-based.

Few examples may clarify the concept. For instance a school, through its fundamental role in educating the youth in environmental and development issues is important for conservation. At village level, water development and sanitation is always a top priority and very much appreciated by farmers for its positive implications. If water availability increases, for instance through spring development or a well, besides improving the water quality and related health problems it may also allow to establish a small village/target group nursery using the water overflow, contributing again to support soil conservation. Reciprocally, the recharge of the well or spring would depend from the conditions of the catchment below which they are located, i.e. its ability to intercept and store sufficient water and thus recharge underground water tables. Accordingly, catchment protection through a combination of physical and vegetative measures would enhance the performance of the well and spring and ensure the provision of a number of other benefits (woody products, grasses, etc.).

Very important for conservation are the agronomic practices and the provision and sound utilization of agricultural inputs. Several agronomic measures would improve soil conservation and satisfy farmers requirements in increasing production. For instance, fast growing improved varieties would considerably reduce erosion, specially at times when the combination of intensive storms and ploughed fields exposes the soil to high erosion rates. Manuring soils would increase infiltration, nutrient exchange capacity and aeration, reduce runoff and soil particle s detachment, etc.

2.1.5 What should be considered in conservation-based planning?

The basic idea behind participatory planning is that selection of soil and water conservation development measures should be based on technical aspects (from the analysis of land resources) and on people s immediate needs (from the analysis of farmers problems, needs and aspirations) in order to be successfully implemented.

A participatory planning approach should try to integrate the views of the farmers and conservationists **so that farmers' primary interests are satisfied at the same time as the conservationists concerns about sustainability and productivity of the landscape are satisfied.**

Planning must **accommodate sub-watershed principles and social aspects related to the area supposed to be treated.**

In this respect, the selection of the planning unit would be essential to tackle land degradation and related food insecurity problems effectively. Accordingly, **the concept of Elementary Territorial Units or UTEs** as units for strategic planning, prioritization of interventions and systematic implementation has been elaborated in detail in Section 3.

The socio-economic analysis should be extremely accurate because of the cultural complexities and variation of agricultural practices according to climatic conditions.

Problem identification should be directed towards survival needs and people s concerns and reluctance to take risks by adopting new techniques that may lead to crop failure during rainfall shortages.

The technical surveys directed to study and delineate the UTEs and the priority village sub-catchment areas to be treated should pay a great attention to rainfall erosivity, intensity, soil conditions, slopes and vegetative cover.

The interactions between bio-physical and socio-economic elements should be clearly understood and analyzed. They would provide guidance for the selection of adequate solutions to social and environmental constraints.

2.1.6 *Adjusting participatory planning to bio-physical and social conditions*

The planning work should be oriented differently based on the following conditions:

(i) For lands occupied and cultivated/used by farmers.

(ii) For lands used by nomads or semi-nomads.

(iii) For abandoned and seriously degraded/desertified lands or lands considered unable to support agriculture.

(iv) For lands located in extremely dry areas where agriculture is considered impossible.

⇨ Planning approaches for (i) should pay attention to all possible means able to sustain and increase agricultural production by increasing water availability and maximizing moisture storage capacity for food, forage and tree crops, thus reducing the risks of drought occurrence. **Under Myanmar conditions, the main focus would be on addressing the problems of this type of lands since they represent the existing main source of subsistence and income.**

⇨ Similarly, a planning approach for (ii) would essentially aim at addressing the needs of pastoralists and their herds, traditionally rather mobile along transhumance (grazing) routes which are the result of decades of experience and adaptation to climate and environmental conditions. The most critical needs are always water and animal feed. The planning and implementation strategy would focus on both improving access to water and its availability (also in terms of number of water points to avoid concentration of animals around few), provision of sufficient amount of feed and of good quality (water harvesting measures for grazing lands and range land management). In the Myanmar Dry Zone the ii) conditions do not apply, at least not in the form of nomadism. However, with the exception of drought animals most livestock are free grazers (cattle, sheep and goat) and availability and access to water and good quality animal feed is limited, particularly at the end of the long dry season. These problems would be integral part of the i) planning approach.

⇨ The third (iii) condition should be viewed as a possible expansion of agriculture in lands considered irreversibly lost or unsuitable for cultivation. It may partly solve the need for extra land and can be viewed as a 100% gain from the farmers/users point of view. A clear example of lands under iii) conditions and rehabilitated are the gullies treated with series of SS dams and checkdams or the degraded areas converted into bench terraces through leveling, filling and bunding.

⇨ Approach iv) does not apply in Myanmar but should be regarded in other countries as a most valuable and essential component of the rehabilitation and reclamation of arid lands.

2.1.7 Monitoring and Evaluation

Being an organized method, by which information is documented and available to all, planning is also an essential part of the monitoring and evaluation system, helping in the management aspects of the resources (human, technical, inputs and others) that are necessary for the sound implementation of the measures proposed in the plans.

2.2 Participatory Planning and Selection and Design of Appropriate SWC Measures

The identification of possible techniques should be carefully done, **involving farmers in the decision-making process and design of the possible measures.** Traditional measures should always be considered.

Since most of the techniques are not familiar to farmers, a **participatory technology development** may be necessary. Measures should be tested first at small scale. If found useful they may be expanded to larger areas. Often the techniques should be tested over a few years time span to find out their performance under different climatic conditions/ variations.

Integration with other line ministries and departments is very important. Agronomists, livestock s specialists, foresters and conservationists should interact together, combining skills and experience, minimizing each other weaknesses and emphasizing their respective strengths. A simple, practical and quality oriented mechanism can be in place in a very short period.

> Concluding, **the methodology aims at the selection of suitable measures and activities in line with the problems and needs of the community and individuals.** The community should be closely involved in the identification of the most important problems, in a suitable order of priority, and the most appropriate and acceptable way of solving them bearing in mind the limiting factors that cannot make all their problems solved at once. Field technicians **should always be realistic in terms of inputs availability and agree to implement activities based upon the constraints.**

3 VILLAGE AND LANDSCAPE UNITS: THE CONCEPT OF PRIMARY TERRITORIAL UNIT (UTE)

The following is an elaboration about the strategic elements related to the bio-physical environment that should be considered for tackling effectively and, if possible, irreversibly, land degradation, accelerated desertification and related poverty in dry zones.

3.1 Definition of Land

Since the UNCED (United Nations Conference on Environment and Development, 1992) Agenda 21, a conceptual shift from the older land/water dichotomy towards an integral concept of the land as a system traversed by water, with land use depending on access to water (among other factors) and at the same time, affecting the passing water in its pathways, seasonability, yield and quality. The understanding of this concept is critical for developing drylands where water availability is the major constraint for cropping and biomass regeneration.

In a broader sense but easy to disaggregate into smaller units land can be defined as follows:

> *"Land is a delineable portion of the earth's terrestrial surface, encompassing all attributes of the biosphere immediately above or below this surface, including those of the near surface climate, the soil and terrain forms, the surface hydrology (including shallow lakes, rivers, marshes and swamps), the near-surface sedimentary layers and associated groundwater and geohydrological reserve, the plant and animal populations, the human settlement pattern and the physical results of past and present human activity, (terracing, water storage or drainage structures, roads, etc.)."*

Therefore it is important to consider the land not only as a physical unit but also as a living and interacting unit which is characterized by a complex and many-faceted set of constraints but also potentials which demands a holistic and systematic approach to development.

The concept of a UTE is thought to help planners and technicians dealing with dry zones to define a correct approach for tackling land degradation and closely related food insecurity & poverty issues. It originates from the original and effective work carried out by an FAO integrated rural development project in the Sahel (GCP/NER/032/ITA), in the seriously degraded, drought affected and food insecure district of Keita in Niger (R. Carucci, 1989). Since dry zones in the world offer a wide spectrum of diverse conditions, the following should not be seen as a set of blank definitions and recommendations but only as a source of inspiration for defining appropriate planning and intervention units for the Dry Zone of Myanmar.

3.2 The Primary Territorial Unit (UTE)

3.2.1 Definition

The term UTE is used to indicate the smallest territorial unit or micro-environment which represents the whole set of biophysical characteristics and problems of a given area. The UTE generally coincide with a number of sub-watershed units which include one or more villages (human and socio-economic component). Each unit can be thought as a specific habitat where most bio-physical and human interactions can be isolated and considered separately from the remaining environment. This categorization does not include land tenure, laws, tax structure and other issues common to a large area, region or even an entire country. Besides, some others elements such as physical infrastructure, customary laws and rights, accessibility to inputs and price-marketing may be specific and represented in one UTE or shared between two or more UTEs, depending on local conditions.

3.2.2 The approach

Integrated and systematic interventions at the level of each UTE can locally induce a favorable and often irreversible solution to the problems of land degradation intended as bio-physical, human and socio-economic. By following this approach, the desired objective is to reverse once and for all the land degradation-food insecurity-poverty trend by attaining tangible results which would be sustained by the rural population because the meet their demand for more land to cultivate, increased water availability and biomass production, better access to inputs and outputs and improved basic infrastructure. The ultimate ambitious scope is to not return to one area or UTE which has been treated because the area would be in a position to be managed rationally and meet the needs of its people in a sustainable way.

The UTE approach is guided by the global vision of the system of series of sub-watersheds which constitute the cluster or larger area of intervention (a major watershed, a large group of villages, a portion or all of a township, etc.). The rehabilitation of the ecosystem of this area is a long term objective, which can be achieved only by coherent and articulated multiple interventions which gradually treat the whole area. This gradual process is rendered possible by the identification and prioritization of UTEs, based upon a pragmatic approach which considers the resources available and the desiderata of the population invited to participate. Although unquestionably linked to soils, vegetation, landforms and drainage conditions delimited by sub-watersheds boundaries, this approach requires considerable flexibility compared to the theoretical schemes and intervention logic which characterize conventional watershed approaches.

This flexibility can be further seen by considering that within each UTE different portions of the landscape or small sub-catchments can be considered separately in order to be treated, for instance to respond to the critical needs of a particular target group or community. After this first response, additional interventions will follow completing the progressive set of actions necessary to rehabilitate the whole area. It should be also emphasized that it is only through the rehabilitation of the land and the improvement of its productivity that other interventions such as basic infrastructure and socio-economic activities would be meaningful and sustainable. Thus, all interventions become interrelated and supplement each other as pieces of a mosaic which progressively becomes more and more significant and comprehendible, the whole process leading to the integrated management and sustainable development of each and every UTE, and ultimately of a wider area based upon the scale of interventions.

3.2.3 Advantages to using the UTE concept

The main advantages in selecting UTEs as units for planning and implementation of development endeavors in seriously degraded and poverty stricken areas in dry zones are summarized as follows:

- The possibility to drastically reduce and possibly reverse land degradation and desertification (and consequently food insecurity) by systematically and effectively treating a significant portion of the territory with an entire set of measures and activities which adequately meet biophysical and social requirements.
- To effectively use limited resources for the development of dry lands. This is to avoid the dispersion of inputs and interventions over large areas and high number of beneficiaries which renders the whole development endeavor ineffective to address the inner causes of food insecurity and poverty which are closely related to the bio-physical environment.
- To inspire, motivate a gain the trust of a psychologically sensitive population which struggles to survive under difficult conditions, and which would respond positively only to effective measures and results, and thus to the removal of existing constraints affecting their livelihood.

- To set up an example for an effective, replicable, participatory and integrated approach for the development of the Dry Zone.
- To demonstrate the existing potential for developing large portions of the Dry Zone in a cost-effective manner, leading to the replenishment of the natural resource base, increase of productivity per unit of land, removal of production constraints and improvement of living standards.
- Enhance access to improved technology and its adoption.
- Increase participation and enhance solidarity mechanisms amongst land users and all partners involved in the development of the Dry Zone.

3.2.4 Limitations of the UTE concept

Strategies and interventions aimed to address wind erosion problems are not conditioned by territorial units and their disaggregation. In this case site specific interventions are required where the phenomenon appears serious. However, it is expected that the long term benefits generated by the rehabilitation of degraded landscapes such as reforestation of hillsides, establishment of boundary plantations and revegetation of gullies within one or more UTEs would also have a positive impact on wind erosion problems.

The identification and prioritization of UTEs requires considerable field surveys and is optimized by the use of aerial photo interpretation and related mapping. This implies skilled manpower which may not be available.

3.3 Village Development Planning Guideline

The present version of the planning guideline does not include the concept of UTE for reasons of simplicity, i.e. to facilitate the planning work at the village level taking into consideration the existing planning capacity and skills of field staff working in the field. However, in its present form the planning guideline can easily incorporate or take into consideration the concept of UTEs for prioritization of areas for planning and effective implementation. Currently, the planning guideline suggests the **village and its boundaries to be taken as the planning unit.** Nevertheless, the guideline also recommends **to take into consideration sub-watershed boundaries and micro-catchments based upon the type and nature of problems and solutions to apply.** Therefore, planning procedures which consider UTEs can be easily seen as an expansion of the existing planning methodology into a more elaborated and systematic form of planning. Defining an UTE is advantageous for fulfilling planning and implementation requirements whenever problems to be addressed extend the boundaries of one village and therefore need a concerted and integrated approach between communities. For instance for community plantations whose boundaries may include one or more villages. In this particular case, one village may agree on the woodlot and another not. Negotiations should then take place until the issue is settled and the upper reaches of the watershed can be treated.

UTEs are normally defined before carrying out detail village planning exercises through the undertaking of rapid bio-physical reconnaissance surveys backed up by aerial photo interpretation and rapid interviews with key informants (village leaders, model farmers, random interviews to villagers, etc.) so that to approximately define different UTEs. Thereafter, detail village plans would be prepared for each UTE, which would allow to further refine the demarcation of the territorial units or provide additional information whether additional communities should be included or not as part of the different UTEs. As mentioned earlier the main advantage of determining UTEs is to provide guidance on which area to focus and prioritize for detail planning and effective implementation based upon severity of erosion, critical needs of land users and potentials for development.

Another possibility is that village level planning exercises are carried out first, systematically and in a relatively large number of communities within a cluster. The identification of both the bio-physical and social links required to define and demarcate the UTEs and their prioritization would occur next, rather naturally and as the result of the perception and knowledge of the interactions between villages, their bio-physical characteristics and socio-economic activities. This approach assumes sufficient time for planning first each and every community, and only subsequently to determine the UTEs. Prioritization in this case occurs only at the implementation stage. A possible drawback is the raising of expectations for those communities which have not been prioritized for immediate implementation but which have been through a detail planning work.

3.4 UTEs, Village Plans, Priority Areas and Logical Sequence of Interventions

Within UTEs and down to village areas there are a number of sub-catchments that can be isolated one from another and treated separately. It is very important that all farmers living within one of such landscape units would agree and interact harmoniously on the measures to be implemented and managed. Therefore, an area suitable for soil bunds would be treated only after all the farm owners of that particular sub-catchment will agree on the measure. The treatment of gullies and drainage lines require similar attention since runoff originates upstream and the wider the catchment the higher would be the peak runoff rates and thus the need to involve and participate a larger number of land users. Design of SWC measures would be based essentially on these factors.

The selection and logical sequence of the different interventions should not be geared by farmers' interests only but also by how those interests can be addressed based upon the bio-physical characteristics of the landscape. For example soil bunds may be requested by a group of farmers from a given area but it may easily happen that implementation cannot take place because their land is located below an hillside and thus likely to be damaged by runoff from the hillside after rains. It is then necessary to involve another group of land users who have rights over those hills or consult the community (ies) if the area is under communal use rigths (grazing, etc.). In this case, problems may be encountered such as the lack of interest in treating the hillside, disputes over use rights, different opinions on what measures to apply on the hillsides and access to labour opportunities, etc. It is only after a clear agreement is reached on what, where, how, by whom and when the treatment of the hillside is going to take place that soil bunds become a viable option for that area.

3.5 Integration Requirements

The example given above brings forward the need for an integrated approach for soil and water conservation. **All landscape units, whether intended as UTEs or smaller portions of a catchment, and their related land uses are connected and influence each other.** The treatment of hillsides would be of importance to control running water downstream into gullies and reduce runoff overflowing cultivated areas. The whole sequence of treating hillsides, cultivated fields, marginal lands and gullies with various physical and biological measures will have a positive influence on water regimes, increase water intakes and replenish water tables that can be exploited with great benefits by the community or avoid the rapid siltation of reservoirs located downstream if any.

Every measure should also be seen on both **advantages and disadvantages** that it may imply. Physical structures need regular maintenance or upgrading that farmers may be reluctant to undertake, the treatment of communal areas for tree planting or biomass regeneration would require control grazing for a number of years, something which herders may be against. Besides, control grazing needs labour and the setup of management rules that may be difficult to ensure and enforce. Within cultivated areas there may be farmers with portions of their land not interested to undertake conservation structures and then making impossible for the others located downstream to implement them for the same reasons explained above for the hillsides. These are few of countless examples of possible constraints deriving from different land users interests and their relationships. In the following sections a set of recommendations and warnings on possible drawbacks and side effectsfor each of the proposed measures is included in their description.

Besides the integration between land uses, it is **also essential to recognize the integration of activities within each land use.** For instance the treatment of hillsides with water harvesting structures such as trenches should be integrated with a proper planting technique, the selection of the right species of trees, the stabilization of the embankment with improved grasses and legumes, control grazing, the weeding and mulching of the trench ditch and the pruning of trees if necessary. Similarly, soil bunds may be stabilized with different trees/shrubs. In addition to soil bunds, contour ploughing, tie ridging and mulching may take place and considerably improve soil moisture content and fertility levels. **Concluding, measures should never be considered in isolation.** Rather, they should be seen within a wider context meant to increasing their efficiency and acceptability at the land user(s) level.

4. GROUP FORMATION AND SOCIAL ISSUES

Group formation in SWC is very important to facilitate participation and planning, ensure a smooth implementation, and enable technicians and land users to follow-up on problems and react on time against them.

This step is integral part of the planning process but is included here to stress the close links between different groups interests and the nature and type of soil and water conservation activities. **Generally, the formation of groups takes place around problems of common interest.**

Traditional group organizations may be the basis for group formation but not always since they tend to be conservative and sometimes undemocratic. In soil and water conservation, group formation is also difficult around social status lines since the hydrology of a given area is not influenced by social differentiation, particularly when applied to the cultivated land. **Thus, the process of group formation should be promoted by the field technician at different stages of the planning process, progressively focusing on target groups clearly interested and motivated to undertake soil and water conservation measures within a landscape unit.** For a given area of interest (SS dams, soil bunds, tree planting, etc.) the interested group should elect trusted representatives or team leaders that may rotate on a regular basis. A larger group may be divided into smaller manageable groups of 10-20 people, in order to facilitate quality control and co-ordination. However, this step should be kept flexible and based upon local conditions, sense of unity of members, commitment and enthusiasm. These factors are difficult to compute but are extremely important in group formation and, in turn, for the performance of the activities being implemented.

These groups should be committed to undertake the required tasks demanded by the nature of the activities. In this respect, each group should be organized on a mutual guarantee basis and agree on all aspects regarding the implementation and maintenance of the proposed measures. A contract should always be drawn up between the group and the supporting organization or, in case of self-help efforts, amongst group members. If payment of incentives is contemplated, the terms and mode of payment, including fines for breaking contractual terms and responsibilities of each group member should be specified in the contract. Those **contractual terms should be made clear to all members during a group assembly meeting and any misunderstanding or disagreement should be settled before implementation takes place.**

The interested group should understand the type of measures to be implemented and the logical sequence of the activities. For instance, construction of bunds in a given area should start from the top of the sub-catchment and not in a scattered mode, specially if the implementation period is approaching the time when first rains occasionally occur. The same applies for community or private woodlots, checkdams and most of other activities.

Within each group and based upon the type of interventions, a **specific organization and training of group members should take place to ensure the group operates smoothly and effectively.** For instance, a group interested in community woodlots establishment by using trenches would have to include two laymen and one supervisor. They should be trained in purpose, design and layout of the measures, provided with an A-frame level and a set of instructions for construction phases and quality standards, record keeping and attendance, etc.. The other members of the group may receive similar training but would also be informed about work norms and provided with tools.

Different groups may have to interact together and agree on what has to be done first. For instance, it is too risky to initiate the construction of a series of soil storage dams below a wide catchment without being absolutely sure that a consistent part of that catchment would be treated as agreed by another group. The treatment of the catchment should precede the treatment of the gully. However, this may not be always possible because of lack of interest to invest time and energy in communal assets or lack of labour at a specific time of the year, etc. In this case, compromises can be found by oversizing spillways able to accommodate heavy runoff or, when this is not possible, by postponing the idea of gully rehabilitation until a concerted action plan is being reached.

Some interventions concern more than one community, for instance the treatment of gullies crossing several villages (for example SS dams in series), or communities sharing the use of wide range of hillsides or grazing lands, etc. Group formation in this case is a particular delicate exercise which may be arranged starting by one community in a chronological order or by involving simultaneously different groups from different villages.

In any case but specially when the second option is chosen, transparent and well defined arrangements and responsibilities for implementation and management should be made between villages, each group made to agree and assigned to a portion of the land to be treated. Specific contracts can be arranged and signed by different village groups together or separately based upon local conditions.

5. USE OF INCENTIVES FOR SOIL AND WATER CONSERVATION

Several conservation programmes use incentives of various kind for the implementation of SWC measures. Some incentives could be materials, used to supplement technical assistance and are provided both as an incentive and to carry out the work effectively (for example agriculture tools). Others are cash or food incentives or a combination of both, often supplemented by sets of essential agriculture tools.

The provision of cash or food incentives for conservation should be seen within the context of an integrated and participatory planning approach, where activities are thoroughly negotiated with beneficiaries. **Inputs are not a problem when properly utilized.** The reasons for failure observed in several conservation projects around the world emphasize on the faulty utilization of food or cash incentives as a main raison for poor performance. They often neglect the context within which such projects were operating, often top-down or coercive, with limited technical capacity and poor extension delivery systems. In such circumstances, farmers often regarded themselves as hired labourers rather than participants, generating a decrease sense of involvement and responsibility which lead to poor standards of work and to poor maintenance (Hudson, 1991). However, within the context of a participatory and technically sound approach, cash incentives or other inputs should be basically regarded as a temporary help and a decent support provided to the poorest members of the community which would allow to treat significant portions of the land within the village and related sub-watersheds in order to restore productivity and sustain the livelihood of most affected strata of the population.

Although soil and water conservation elements are part of the indigenous knowledge, and countless examples are found in the Myanmar Dry Zone, they are often not anymore sufficient to cope with the fast deterioration of the land-based resources. Many land users, though well aware about the negative effects of erosion and other forms of land degradation, can not afford the luxury to spend energy or labour and other inputs to properly address these problems because they are constantly struggling against survival matters.

As mentioned already, local coping strategies are not, to say the least, environmentally friendly and are aimed to supplement income rapidly. Charcoal making, cultivation of additional land on steep slopes, encroachment into natural forests, overgrazing, utilization of crop residues as combustible and forage, shortening of rotations and countless number of other practices are the visible explanation of what poverty can generate and on how poverty is, reciprocally, exacerbated by the deterioration of environmental conditions. Within this context the use of food aid or cash for soil and water conservation measures should be focusing on assisting those resource poor households whose food security is threatened and thus decrease the necessity of selling productive assets which would decrease future productivity (Frankenberg and Goldstein, 1992).

Therefore an approach that would rely only on demonstrations and farmer to farmer extension with the hope of adoption and dissemination is not likely to work, at least not for most soil and water conservation measures. Some of the farmers may pick up a few activities, mostly those who can afford it in terms of labour and cash, but unlikely the poor small scale farmers, certainly not the landless. Accordingly, for several of these works there is a need for capital injection & investment, in the form of agriculture inputs, cash or other incentives required for carrying out labour intensive works which otherwise would be implemented at a very small scale.

It should be reminded that most SWC measures required to increase availability of cultivated land or increase the existing land productivity in dry zones, specially those already in a state of advanced degradation are, by their nature and extent of the area needed to be covered, labour intensive. They would be designed and implemented in view of the need to rehabilitate and reclaim considerable portions of land, but mainly to harness scarce water resources which are considered by farmers the main limiting factor to production. This means intercepting and trapping rainfall effectively, control erosion and safely evacuate or use excess runoff wherever required. The use of cash and other inputs is to be seen within these circumstances, i.e. the need to make substantial changes in terms of conservation and production at a significant scale.

In the Myanmar Dry Zone, the FAO Project MYA/99/006 which use cash for work for supporting most conservation measures recognizes the fact that under current circumstances of chronic poverty and appalling land degradation it is unrealistic to expect land users to undertake a comprehensive, systematic and labour intensive effort in conserving and developing environmental conditions.

Regarding credit for conservation, a move from cash grants to soft loans is an option that can take place gradually, as soon as results in the field are consolidated, food insecurity alleviated and land users interest towards conservation aroused by the benefits shown by the different activities.

Very important is also the initiation of mechanisms able to stimulate self-help efforts, on a voluntary basis. There are always opportunities, particularly if the group organization is well done and consolidated, to find periods of the year where some voluntary work may be possible to be undertaken. Soil and water conservation on a voluntary basis should start in the form of solidarity field days, acts of goodwill, a special form of donation (Buddhist tradition) and social events. The efforts gradually increase until entering into a routine pattern of works to be undertaken on a regular basis. In this respect, the motivating role of the field technician would be very useful. For instance, the whole community may reclaim one portion of a gully every year and the outputs from their efforts may be used for donations to social events and religious festivals. In the same way a two-three days conservation campaign for trench digging and tree planting on hillsides where a small Pagoda may be built is another option. On cultivated lands, the voluntary work would gradually expand after results from previous years clearly show substantial benefits. As farmers start to perceive conservation as a productive activity they automatically increase their voluntary contribution.

Concluding, incentives are important and should be used whenever required but only temporarily and only when self-help efforts attitudes are observed within the community.

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Conservation should not take place where there is a dominant attitude of dependency towards cash or other inputs. After 1-2 years of implementation, cash incentives in the form of grants may shift to a form of soft loans and thus create revolving funds for conservation. Self-help endeavors should gradually increase and become integral part of farming practices.

6. PARTICIPATION IN THE DESIGN AND IMPLEMENTATION OF SWC MEASURES

Consultations with local land users on **what, where, why, how and when to implement** conservation measures is perhaps the most important step of the planning approach for conservation-based development. This step of the planning procedures is explained in the methodology for village planning and is mentioned here in view of their practical implications in the selection, design, layout, construction/establishment and maintenance/management of the various soil and water conservation measures listed in Part V. Ultimately, these additional recommendations should further strengthen the planning stage and guide technicians and land users to implement sound and effective conservation measures.

6.1 The Importance of Flexibility in the Design of SWC Measure

What should be always kept in mind is that land users are **rational** people, continuously making decisions and adapting their way of doing things to the changes that may occur to them. Farmers place more emphasis on short term planning because their own subsistence is understandably their first priority and this has immediate implications on their level of motivation towards addressing land degradation problems. Most land users, particularly in dry lands where food insecurity and land degradation proceed in tandem at a fast pace, need to cope with the day-to-day survival needs in order to feed themselves and their families. Since this often takes place at the expense of land-based resources (i.e. cutting trees, making charcoal, selling out crop residues, etc.), it is difficult to convince poor households to stop their practices and to shift to a new set of measures and management practices that look sound from the environmental point of view. In this case, field technicians should be flexible in suggesting techniques that would not jeopardize farmers income but, on the contrary, alleviate some of their short term problems as well as conserving soils and water. It is not an easy task and it may require a slow and gradual process of negotiations, discussions, compromises and support.

Flexibility occurs not only during the choice of the measures but during their design, layout and construction. An original design or layout may be first accepted and then changed by the land user(s) after additional thinking. Land user(s) may simply change his/ their mind after reconsidering the effects of the proposed measures on production levels. The design and layout may also change if better ideas are brought forward by either field workers or land users. It may also happen that a given measure implemented with certain criteria is modified during implementation to accommodate unexpected problems or needs, depending from what technicians and land users judge is necessary to attain the desired objectives. If any conflict of interest occurs, field staff should immediately discuss with land users (and vice-versa) to change the course of action and add the required modifications. For instance, the realization that soil bunds constructed in a certain type of terrain may not accommodate the amount of runoff likely to be generated between bunds should trigger the wise decision to reinforce them by stone risers and spillways. However, farmers may be then reluctant to provide extra labour for such modifications unless some sort of payments are envisaged. Through frank discussions field technicians should try to convince them and rework the previous targets based upon the resources and time available. **It is better to implement less activities but of good quality than to take unnecessary risks and fail on a wide scale.**

Flexibility is also important as field topography varies greatly from site to site. Soil characteristics within fields also change, demanding new designs for new conditions.

6.2 Initiating a Learning Process

The learning process is based on a series of attitudes and prompt reactions to results that field staff should have whenever SWC measures are implemented. To support this task, a simple and effective monitoring and evaluation system would help and should be established, both at the technician and land user level in order to evaluate results and provide timely changes if necessary. But **a learning process is also based on field perceptions, particularly about changes occurring to land users in terms of attitudes towards SWC, i.e. their willingness to expand or reject them, the pace of adoption and transfer to other land users, etc. It also means to ascertain how measures can be further improved and continuously look for additional ideas and means for refining the new packages.** It means to be curious, open-minded, creative, generous and ambitious to both protect the environment and help people.

Concluding, field technicians should not think that a series of training courses and occasional field surveys and discussions with land users will make them good conservationists. Although many would agree on this comment, reality shows that most of the time this is exactly the attitude that field staff develop after spending a few weeks or even a year in the field doing SWC. Soon, assumptions on what is best for the farmers often start to prevail on common sense and humility. The learning then stops and mistakes start to occur.

The purpose of this short section was, besides the obvious recommendations on follow-up and monitoring of the performance and impact of the different measures, to warn field staff not to fall into the trap of overconfidence and target-thinking. **Field staff should remember that quality is the precondition for quantity and not vice-versa and that there are no short cuts for sustainable and sound conservation-based development.**

7 THE IMPORTANCE AND ROLE OF TRADITIONAL KNOWLEDGE IN SOIL AND WATER CONSERVATION FOR THE DESIGN AND IMPLEMENTATION OF SWC MEASURES.

7.1 Characteristics of Indigenous SWC Measures

Traditional or indigenous measures are not simply structures defined by precise engineering parameters; they are the sum of practices involved in managing soil and water in agricultural settings and they also include agroforestry, agronomic and tillage practices. Technologies arise out of particular set of historical and social circumstances, different people have different attitudes and commitments to them and, because of the dynamic influences over their origin and maintenance, they evolve and change continuously (Ian Scoones et al, 1996).

Most of local SWC practices have designs that reflect their multiple function (Reij, 1991 - IFAD) to fulfill local interests and needs. Their complexity tend to increase

based on their capacity to improve production of high-value crops, protect valuable and fertile fields and, for dry lands, decrease the risk of crop failure. It is not a coincidence that in Kyaukpadaung township of the Dry Zone, sophisticated SWC measures across gullies such as the soil storage and overflow dams are so much valued by farmers. In best circumstances, these structures allow paddies to be grown and at least two crops can be produced in one season (rice - sunflowers/chick peas..). Even in drought years, some yield is ensured by the plots behind the dams whereas crops in open fields usually fail entirely.

Example of traditional conservation measures: A soil storage & overflow earth dam

It is difficult to find uniform SWC practices unless topography and soil types are similar and farmers production system is also similar. This does not often occur in dry zones, where soils and topography are changing one or more of their characteristics from one field to the next one. This is further emphasized by land degradation levels and differences in land holding size and social status of land users. A poor farmer would likely have less capacity to invest time and labor in protecting his field than a better-off farmer.

Traditional SWC measures are the result of a gradual process of experimentation and adaptation rather than a set of standardized measures designed and implemented in one go. For instance, traditional stone bunds are constructed step by step and only get their final shape and dimensions gradually, over many years. Their construction is also adapted to levels of labour and materials available. This also offer farmers the chance to observe the performance of the measures and introduce changes wherever necessary. In this respect, a huge number of possible configurations are observed, such as different lengths, widths and heights, spacing and materials used for construction.

7.2 Dynamics of Change in Traditional SWC

Part I of this guideline explained the changes occurring to most dry zones in terms of land degradation and environmental damage. Whether triggered by major social disruptive events, increased demographic growth, land reforms, market crisis, shift to commercial patterns or by climatic changes, **land user practices have changed and modified to**

meet new pressing demands for food and income. Former SWC are often not anymore in balance with the new situation and thus unable to control runoff and erosion effectively.

A clear example is what is currently happening to cultivated fields located below hillsides that were formerly covered by forests and are now cleared for cultivation purposes. Those terraced fields, resulting from decades of patient and hard work, are now recurrently damaged by runoff from the upper lands. Besides, most of the farmers cultivating the hillsides are often the poorest members of the community, struggling to survive, and then with limited capacity to invest time and labour in conservation.

In the Dry Zone, traditional SWC measures are important and contribute to control erosion that otherwise would be even greater than what is actually observed. Nevertheless, its is also obvious that traditional methods cannot cope with current land degradation trends and are either progressively abandoned or becoming less effective. Then, imposed by survival needs, other farming practices tending to overexploit the land replace the old ones. It should be understood once again that such an abuse made to the land is never driven by ignorance and deed but only by need and, at a certain level, desperation and no choice perspective.

7.3 Traditional Practices as a Source of Knowledge for the Design and Implementation of Soil and Water Conservation Measures

Regardless of their performance, traditional experience and knowledge in SWC and farming should be capitalized by field technicians and used effectively to identify, select, design and implement improved SWC measures.

Soil and water conservation packages should be tailored around the specific and accumulated knowledge which farmers have. Farmers farming practices, which are the product of local circumstances. evolve based on their perception on what is doing well and what is not, on what to do to improve something and what can not or is impossible to do under the existing limitations. These limitations are important to know. They are often the key to success. Some of the limitations may be technical, financial or related to tenure, etc. In many circumstances they are possible to solve or partially alleviate through awareness, training, involvement of government institutions, etc.

In the Dry Zone, most of the SWC activities currently introduced and implemented by the Dry Zone project (MYA/99/006) originated from farmers experience and willingness to overcome the constraints affecting their adoption and dissemination. For instance soil bunds, stone bunds, soil storage and overflow dams, compost making, tree hedgerows along boundaries, etc., have been inspired by local knowledge and are the result of continuous negotiations, observations and discussions with land users.

In case of new techniques, they should be carefully applied and only after having explained to land users the possible advantages and disadvantages their introduction may imply (additional labour, time, etc.). Preferably, and unless land users demand for their wide scale application, these measures should be tried first at small scale and their performance evaluated over a period of one or few years, depending from the activity and the possible modifications that may be necessary to apply.

The appreciation of local knowledge and adaptation of improved methods to local conditions should not be seen as a criticism to scientific methods and research

efforts. They remain important and of invaluable use. What is emphasized here is the danger of standard designs and approaches for SWC which are sure to fail in a dynamic and complex environment such as the one characterizing the Dry Zone. It is also believed that measures of good quality and performance can be easily obtained if they are understood and assimilated by land users. For this very purpose, the recognition and promotion of existing knowledge and in-built traditional skills is often the key to improve, develop and manage technological packages for SWC. Accordingly, there would be little doubt about their maintenance and rational improvement over the years.

8. SUSTAINABLE AND REPLICABLE CONSERVATION LAND

Words and issues such as environmental sustainability, sustainable environmentally-friendly development.., etc. have become the necessary condiment of most if not all recommendations and suggestions provided by experts dealing with the agricultural sector (including conservation), during the formulation, appraisal, implementation and evaluation of conservation projects or projects having an important conservation component. Unfortunately, what is often neglected or superficially indicated is how to achieve environmental sustainability. This happens for reasons going from lack of time to appraise local conditions with sufficient accuracy in order to indicate possible solutions, to lack of field exposure, limited expertise available to comprehend the complexities of farming systems in their entirety and then formulate appropriate strategies for intervention, and limited capacity to interpret the dynamics on to which extent and how degradation occurs (causes). This is particularly true when it comes to identify and analyze the linkages between such detrimental trends and the livelihood of the rural population. Linkages which are most of the time not known with the sufficient degree of accuracy required to respond to the problem effectively and answer questions on what type of interventions are needed and especially how to plan and implement them.

The greatest difficulty lasts in the last two questions since the answers are related to an entire array of technical and social disciplines and should be addressed through a consultative approach. There are also other important aspects that should be contemplated such as land tenure issues and policies, skills and manpower available, inputs and logistics, etc. In the past and recent years, several conservation programmes and projects failed because one or more of the above issues was not taken into consideration. The same occurred to many programmes or projects directly or indirectly related to agriculture and rural development that neglected the environmental issue or were not able to address it comprehensively (irrigation schemes, road construction, water supply etc.).

8.1 Sustainability

> *"Sustainability comprises the long-term maintenance of the productive use of resources and the integrity of the resource base. A sustainable resource base is one that is neither significantly reduced in the long-term, nor damaged in its function. Future generations can still use the same resources".*

Sustainable development of agriculture in semi-arid regions means satisfying the needs of the local farmers while conserving resources and maintaining the quality of the environment. In order to find out if measures are sustainable, one has to find out their effects on these resources, whether they are preserved for future use or not.

8.2 Replicability

"Replicability, by contrast is concerned with the ease of adoption of the intervention through traditional extension practices. Replicability subsumes interventions closely related to traditional practices and of low cost" (D. Kahan, 1998).

Although this is generally correct, the concept should be extended. There are a wide number of practices which were not traditionally used but have been rapidly accepted by land users after their introduction. **Therefore, in addition to improve or expand valuable traditional practices, what is also important is the capacity of traditional setups to absorb and incorporate new technologies and practices based upon their effects on the household economy.**

It is also often assumed that if measures are not replicated by the land users themselves they are not good. This may become a misleading concept, a way of seeing development as a mere utopia of good advice-good response which reduces the whole process in endless series of dialogues, meetings and ephemeral enthusiasms for expectations which will often never materialize. A bridge or a new road are likely to be assets which are not replicable (let alone constructed) without capital investment but are surely necessary, sometimes vital for the economy of an area. **Similarly, some conservation works are easy to replicate without inputs, others need some support while others can not be realized without inputs.**

In dryland areas affected by severe land degradation and rapid reduction of the natural resource base and related productivity, **replicability and sustainability should then be also thought in terms of management and perpetuation of the measures being selected and implemented by land users rather than only what farmers can do by themselves within a determined set of constraints.**

For instance, the construction of soil storage and sedimentation overflow dams across gullies allow to convert waste land into productive benched fields (see Part V - SS dams), often paddies, which are extremely valued by farmers. These are structures small farmers are familiar with but few can afford because relatively expensive. The provision of external inputs (government, projects, etc.) jointly with farmers own contribution would permit to construct these structures, render fertile the gully, make it productive and raise income of beneficiaries almost immediately. Once established, the asset is managed, sustained and even improved without problems because of the existing (traditional) knowledge about the technology. **Therefore, soil and water conservation is also to be seen as a capital investment effort wherever this is necessary and applicable.**

8.3 Strategies to Achieve Sustainability and Replicability

To achieve sustainable and replicable soil and water conservation measures, two main strategies are often envisaged.

8.3.1 Demonstration sites

They are assumed to be low cost and low risk activities, limited to small areas and meant to prove the technical effectiveness and social acceptability of the tested measures. Under Myanmar Dry Zone conditions, they are based on the assumption that soil and water conservation technologies are new and that a cautious approach is better than a wide scale operation. In this case, the adoption and dissemination of conservation measures is slow and would occur mostly through extension staff, farmer-to-farmer transfer of technology and training. Main limitation reside on the unit or scale of demonstration, i.e. one or more set of technologies may be effective only if applied over a large area (woodlot, gully control + terracing, bunding, windbreaks, etc.). This is especially true when important side benefits such as recharge of water tables for drinking water are considered. In this regard, a unit for demonstration should be determined based on the set of objectives to be attained. For example, compost making for demonstrating improvement of fertility may be achieved in a small plot. However, a wider objective such as supplying enough raw materials and sufficient water for compost making to be adopted on a wider scale (for instance an entire village) would demand a greater effort of rehabilitating hillsides, improve pastures, control grazing, checking gullies and treating cultivated lands with a wide range of measures over a large area. In this case the unit for demonstration is certainly wider.

8.3.2 Implementation approach

The strategy is to cover as many sites as possible bearing in mind that a certain degree of failure would be compensated by a larger degree of success provided that measures are carefully negotiated and approved by land users but also implemented with the greatest of attention paid to their design and construction standards. Besides, all physical structures should be integrated with biological measures for maximum stability and production, i.e. bund stabilization, tree planting, forage improvement in reforested sites, control grazing, agroforestry, etc. If proven useful, dissemination and wide scale adoption of conservation measures is fast. This occurs mainly through the means of farmer-to-farmer transfer of technology, field days, training and the support of incentives for labour demanding works. An implementation approach may be expensive since incentives are often required for labour. The incentive system is required in particular to address the traditional pattern of seasonal migration of labour to other areas and address chronic food insecurity problems. The main advantage of this approach is that it facilitates a quick and efficient rehabilitation of the land provided that incentives are carefully used, technologies are appropriate and participation of land users in decision-making, planning and implementation is guaranteed throughout the whole process. However, the costs for this approach tend to be higher than those involved in a training and extension approach (D. Kahan, 1998).

The two strategies are not mutually exclusive. **Because of the difficult conditions existing in the Dry Zone, most land users have neither the time and the inputs nor the inclination to address the complex and demanding problems related to land degradation.** It is then suggested to adopt a combination of these two approaches, i.e. testing and demonstration in case of new technologies and wide scale dissemination of measures derived from traditional practices that are more likely to be understood and thus rapidly adopted by land users.

Besides the conceptual terms and their meaning, the **answer** to the question on how to achieve sustainable and replicable soil and water conservation works **resides in the field**. Field work, as explained already, should start by establishing good relationships with land users, an essential element to understand their problems and gain their trust. It means also hard and patient work in appraising bio-physical and socio-economic conditions, able to guide land users and technicians towards a realistic and effective set of interventions. The more field experience field staff is able to get the higher would be the possibility of achieving something sustainable and replicable.

Measures inspired from highly valued traditional technologies are likely to be accepted because farmers are already familiar with their expected benefits and their management requirements. In this respect they may be seen as to have more potential to become sustainable and replicable. However, this should not be considered always true since there are a number of new technologies that can prove to be very useful and become integral part of the local practices in a short period of time.

There are also a number of **external factors** (policies, tenure, prices of agriculture produce, labor availability, etc.) that may influence in one way or another the sustainability of an existing or improved land use system. Those are beyond the capacity of field staff to solve and thus are just partially considered in several sections of the present guideline (Part I, Part IV, Part V). There are however a number of local initiatives able to alleviate some of these constraints that field staff should always remember. For instance, land tenure issues can be addressed at the village tract or township level for solving conflicts and settle disputes over property and use rights. Better marketing can be achieved if accessibility to market places is improved; a new road may be then constructed by the community, a project or through the involvement of a government institution.

Conservation should never be dissociated from production. This is perhaps the essence of sustainable and replicable soil and water conservation. In spite of the existing constraints, every effort must be made to develop practices which do not only conserve the soil but also provide short term and clear benefits to the land users. This is not always possible, particularly for activities such as woodlots which take several years before providing the expected benefits and require considerable care in the meantime. However, a combination of activities within a wider area, which in addition to the woodlot would include measures such as stabilization of structures with improved grasses, reclamation of gullies or waste land for productive uses and improvement of existing cultivated land (fertility, moisture content, etc.) makes the whole system more productive and then acceptable to the land user, even if for some activities and land use the benefits are medium or long term.

PART V: SOIL AND WATER CONSERVATION MEASURES FOR THE DRY ZONE

Soil and Water Conservation in the Dry Zone of Maynmar

1. INTRODUCTION TO SOIL AND WATER CONSERVATION

1. 1 Principles

Soil and water conservation (SWC) in arid and semi-arid zones should be viewed as the necessary support to sustain and especially increase food crop production, forage production and growth of trees based on the different or combined main type of land use.

- In spite of low and erratic rainfall and limited number of crops that can grow under dry zone conditions, there are a wide range of conservation measures that can be applied with success. **Those measures are both physical and biological, the first often supplementing the second and vice-versa.**
- **Field staff is then responsible to initiate a participatory process** which would lead to the identification and selection of suitable technologies for soil and water conservation in line with land users desires and environmental principles of sustainability.

1.2 Physical versus Biological Measures: an integration issue

In dry zones, the question whether physical conservation structures are appropriate or not is superfluous. Several conservationists tend to generalize the commonly assumed idea that only biological measures should be considered and that physical structures are usually not accepted by farmers and do not generate short term benefits. This may be partially true for high and medium rainfall areas (although with reservations) but certainly does not apply to the dry zones.

- The rainfall pattern of arid and semi-arid areas, characterized by short duration destructive showers, and the erosion-prone soil conditions of most of these areas are serious constraints for biological measures. Physical barriers are then often necessary, as a precondition for the introduction of improved agronomic and soil management practices, and agroforestry measures. Besides, in several parts of the world semi-arid and arid areas, the very existence of agriculture is permitted by old, traditionally made, outstanding physical measures such as terracing, well integrated with complex and effective biological practices. In all circumstances, biological measures enter together or after the establishment of physical structures. In this respect, the introduction of physical structures alone, although positive, would not be as effective in controlling erosion and increasing production levels as they would be together with biological measures.
- **In the Myanmar Dry Zone, as well as in most of the arid and semi-arid lands of the world, soil and water conservation measures are to be introduced in already degraded environments, with high degree of poverty and low incomes.** Within this challenging context, how to involve land users in soil and water conservation? How can they participate in activities for land rehabilitation that often requires the whole community commitment and effort? When would the pace of land rehabilitation overcome the pace of land degradation? Would incentives be necessary to achieve conservation? In which form and for how long?
- To most of these questions some answers are given in the following sections. The most important element to consider is that soil and water conservation is not an easy task and surely not to be considered as a precooked set of measures ready to be applied based upon technicians judgment.

2. DESCRIPTION OF SOIL AND WATER CONSERVATION MEASURES FOR THE DRY ZONE

The following sections include a range of SWC measures suitable for each main land use type, namely cultivated, grazing, forest and gully lands. However, this distinction is mostly artificial because in the Dry Zone the land if often of multipurpose use. For instance some lands can be both cultivated and then grazed, fallow and grazed for many years; others are grazed and used to supply woody materials; gully lands can be used for cultivation, grazing and collection of wood, etc.

For didactic reasons and simplicity, the measures described in this guideline are inserted in one of these four main units of land use but there would be clear indications of their relevance for other land uses and integration requirements both at the level of their selection, design, implementation and management.

A. CULTIVATED LAND

2.1 Soil and Water Conservation Measures for the Cultivated Land

Soil and water conservation measures for the cultivated land are here divided into two main sections, **physical and biological** measures respectively. These two main domains of soil and water conservation are equally important and should be integrated. The basic difference is on their effects in controlling erosion:

›physical measures manage runoff whereas

›biological measures mostly manage rainfall (splashing effect of raindrops).

In principle, the following sequence should be looking at:

. First manage rainfall,
. Then manage runoff.

The presence of a good surface cover, which reduces soil splash, and the maximization of infiltration, which reduces the volume and hence, the velocity of surface runoff, are the main elements for erosion control. Only when runoff is unavoidable and consistent that additional conservation measures will be needed.

In **dry zones, this sequence is not always possible because of the constraints already mentioned in several sections of the guideline. The sequence may even be reversed to a certain extent. For instance, the water harvesting effect of most physical structures stimulate biomass production** which can then be used for improving surface cover, soil structure and organic matter content and, hence, reduce splashing effect of raindrops.

However, all possible means should be envisaged to combine, from the very beginning of implementation, different biological and physical measures able to complement and supplement each other effectively and thus significantly reduce erosion and increase production levels.

Physical SWC measures

- Objectives, purpose and nature of physical SWC
- Physical SWC measures **focusing on maximum water retention**, increase soil profile moisture storage capacity and eventually evacuate excess runoff
- Physical SWC measures **focusing on increasing water availability** onto cropped areas, increase soil profile moisture storage capacity and eventually evacuate excess runoff

Biological SWC measures

- Agronomic conservation measures
- Soil management practices
- Vegetative conservation measures

2.2 Physical Soil and Water Conservation Measures

Before starting the description of each and every measure, it is important to briefly describe the basic tools or instruments and estimation methods that are required to design, layout and construct soil and water conservation measures. This applies to all land uses and not only for the cultivated land. The following are simple cheap instruments and methods, most of which can be fabricated locally. Annex 2 will elaborate further on the most important instruments and their utilization for conservation purposes.

2.2.1 Measurements

(i) Measuring slopes

Slopes can be measured by using a **clinometer or different type of line levels.** Cheap clinometers can be used for an approximate reading of the slope range, which is normally sufficient to design conservation measures at the farm level. They are not recommended for precise layout such as for graded structures and irrigation canals. A paper clinometer, showing degrees and percentage slopes can be made in a few minutes. A range pole clinometer is more accurate since it is placed above a stable stand.

(ii) Making contour or graded lines

Slopes can be measured with accuracy by using a **water line level** and applying the following formula:

$$\text{Slope\%} = \frac{\text{Vertical interval in centimeters}}{\text{Horizontal distance in meters}}$$

- A classic water level placed in the middle of a rope attached at the extremities of two poles at a determined distance allows a quick estimation of the slope.
- **Abneys bubble levels** can also be used since they include a slope range reading device.
- Slopes can also be read using an **accurate altimeter and a distance meter** (or simply a meter tape) and other types of more advanced levels. For practical uses, the line level is recommended for field work.

The water line level is the most commonly used instrument to make both contour and graded lines. Distances between two poles can easily be shortened or widened based upon the nature of the terrain. In areas where slopes tend to change continuously within a short distance, it is recommended to fix the two poles at max. 10 feet apart, whereas in uniform single slopes they can be extended to 30 feet apart max.

Another level of practical use is the **A-frame, very useful in difficult terrain (changing slopes, depressions), specially to layout small structures. It is also an essential tool to check the leveling of the top of the bund embankment and the bottom of the water collection ditches.**

Contour lines can also be made by using numerous types of levels (abney, various optical levels, etc.)

(iii) Measuring distance

In most cases, a simple meter tape (50-100 m) is sufficient. There are also range meters (expensive) and pedometers that can be used, with various degrees of accuracy. In absence of meter tapes and not relying on foot steps, a rope with knots at regular intervals can be also used.

(iv) Measuring soil depth

Augers are normally used. They may be not available and thus you should either dig a trench, observe a nearby gully profile or ask the farmers for such type of information. What is important to know is the workable soil depth or the soil depth useful for plant growth, not inclusive of hard subsoil, pans and unconsolidated parent material.

(v) Measuring the area

In absence of large scale topomaps and aerial photos, measure the area (in acres) by using a direction compass and by measuring distances (see village planning guideline). Then convert data into a map and use a dot grid square for measuring the area (convert into acres based on chosen scale). For small areas, measure the approximate perimeter and convert into acres. Check your results with farmers; they normally know with sufficient accuracy the area of their plots.

(vi) Measuring altitude

An altimeter is usually required for accurate measurements (feet range). For rough estimation consult topomaps.

(vii) Measuring rainfall

Collect data from the nearest meteorological station. In your working area, construct a simple rain gauge by using a funnel (2-3 inches diameter) and a graduated plastic tube (graduation based on ratio circumference of funnel/tube). Then train farmers to read and collect rainfall data, including approximate maximum rainfall intensities within one hour from the beginning of the rain shower.

(viii) Estimating vegetation cover

Use simple grid systems calibrated in % for quick reading and approximate estimation of surface cover and potential erosion (C and K factors). Use the grid proposed for the Erosion damage assessment form (page 50)

(ix) Estimating texture

A bottle of water and your hands are enough. Refer to Annex 2 for sampling texture classes.

2.2.2 Objectives, purpose and nature of physical Soil and Water Conservation Measures

It is essential to define the objectives before considering which type of structures to use. First, any protection works must be appropriate for the intended crops. A system may be excellent for tree crops but unsuitable for annual crops. Second, the system must suit local conditions. Soil depth, slope and rainfall determine whether a maximum infiltration scheme or a rainfall multiplier system are practical, or whether surface runoff must be managed and eventually evacuated. It is more important to understand these principles and how they can be applied to particular conditions than to follow even the best instruction manual.

If excess runoff is expected to occur with damaging intensity, **physical works are appropriate to control water movements and limit its erosive capacity.** In dry zones, they are also of extreme importance for water harvesting purposes, for the provision and retention of additional water into the cropped area is essential to the growth of crops, trees or grasses. In all circumstances, they should be seen as a support to good farming practices and an integral part of the conservation package.

Physical structures have the prime purpose to divide the natural length of a hillside slope into shorter sections. This limits the volume and velocity of runoff that each structure must constain (level) or guide (graded). The reduction of slope length reduces the chance of runoff gathering into constricted flow lines and so reduces the probability of rills and gullies forming. **Slope steepness** is an important consideration because it affects the downslope velocity of runoff and, hence its capacity to scour and transport soil.

Contour structures are normally followed by contour ploughing and planting. When planting is done on the contour, tillage, weeding, and other operations tend to produce small ridges that impede the downslope flow of runoff and gives the water more time to soak in.

The type of barriers across the slope, level or graded, vary according to their specific purpose. Where the purpose is to detain all runoff, impermeable barriers of appropriate size are set out on the contour. These can be either continuous or discontinuous (preferable) across the slope. They are suitable in deep soils, with sufficient infiltration and storage capacity and gentle slopes. On steep slopes or shallow soils, in soils with textural problems, etc., it is better to either provide the structures with excess water disposal devices or to construct semi-permeable/permeable structures that slow down velocity and reduce erosion. When the purpose is to carry runoff away, impermeable structures are set out on gentle gradients (graded bunds, cutoff drains, etc.) across the slope to guide the runoff to suitable discharge points (stabilized gullies, waterways, rivers, etc.).

2.2.3 Measures for maximizing water retention

As explained in Part IV, most of the SWC measures proposed for the Dry Zone will be introduced to protect and conserve existing cultivated fields. In this case, the application of rainfall multiplier system (see 2.2.4) will be unlikely to take place in already cultivated fields. The latter will be described within the context of land rehabilitation and land reclamation efforts.

Based on this simple consideration, SWC measures will have the prime purpose of controlling runoff velocity and erosion. **These measures are meant to make the best use of available rainfall, relaying on the fact that the amount of water and nutrient loss by surface runoff is a main limiting factor in crop production.**

The individual measures are decribed in the section starting on Page 155. The list of measures and the technical specifications, however, should be viewed as indicative and would need to be refined based upon additional field experience and results.

2.2.4 Measures for increasing water availability

Physical SWC measures focusing on increasing water availability onto cropped areas, increase soil profile moisture storage capacity and eventually evacuate excess runoff.

2.2.4.1 Purpose and objective

In Part III, the strategy for increasing water availability onto cropped areas has been described in detail (page 64). The measures should be seen as a potential for abandoned lands or lands considered impossible to cultivate because of severe rainfall deficits. In the Dry Zone, considerable portions of marginal lands with depleted and crusted soils can be rehabilitated with rainfall multiplier systems.

Most of the measures described in the following section are labour intensive and thus justified only in situations where land users are willing to reclaim lands for productive uses. Injection of capital is often required for the construction of rainfall multiplier systems since land reclamation of severely degraded lands implies drastic, costly action, usually including changes in land use, soil improvement and specialized-labour intensive works. Labour should be available and technical support ensured for the entire duration of the design and construction stages.

2.2.4.2 The productive use of water from catchments / runoff areas

The measures described are also named by several writers on Water Harvesting measures. There are a number of classifications of rainfall multiplier systems. For instance micro and macro catchments, internal and external catchments, etc. Internal catchments are where runoff is produced within the cropped area and external catchments where runoff is produced outside the cropped area (from hillsides, gully sides, etc.). For reasons of simplicity the following would only elaborate on the main techniques considered of relevance under Maynmar Dry Zone conditions, mentioning for each of them the principles and type of method adopted and their technical specifications.

2.2.4.3 *Selection of method in the Dry Zone*

Internal catchments

Long fallows: A number of fallow lands with shallow soils with limited water retention capacity can be rehabilitated using rainfall multiplier systems (internal catchments) for conserving crops such as legumes and low fertility demanding crops such as millet. Eventually, part of the crop residues should be left for mulching.

Marginal lands with surface crusting problems, low infiltration and low moisture storage. If soil conditions under crust layer are satisfactory (soil depth > 1'), a number of crops can be introduced together with the application of fertilizers, compost and, after harvesting, mulching to improve surface conditions.

⇒ For both land use types, soil/stone bunds with runoff/runon areas and conservation bench terraces (continuous or intermittent) with runoff/runon areas are suggested. Supplementary measures would be tie-ridging, contour furrows, deep tillage (ripping), surface and stubble mulching, compost application, improved rotation, ley cropping, etc.

External catchments

Treatment of gully bottoms using external catchments and flood water harvesting within stream bed. New cropped fields would be then generated as a result of the deposition of sediments and availability of water by the means of:

⇒ Measures such as earth/stone faced sediment storage dams provided with spillway placed across the gullies at regular intervals.

Natural runoff from hillsides into cropped areas or marginal lands/fallow lands.

⇒ Stone faced/soil bunds or stone bunds provided with spillways are placed in the fields below the catchment area.

Collection and divertion of runoff by the means of:

⇒ Cutoff drains/hillside conduits onto cropped areas or rehabilitated lands by using overflow bunds, or bunds provided with spillways.

2.2.4.4 *Estimation of catchment area (runoff)/ cropped area (run-on) ratio*

The purpose of designing rainfall multiplier systems is to get the **best ratio of area yielding runoff to the area yielding run-on.** In Part III a rough method for calculation of runoff/run-on areas is provided based on the type of soils and crop water requirements. Whenever possible estimations should be done accurately.

In absence of research data, in Myanmar Dry Zone conditions, the ratio of **internal catchment area/cultivated area is likely to be 0.5:1 to 1.5:1** (average 1:1). Since design rainfall (67% probability) is at least of 400 mm and, for internal catchments, the runoff coefficient is around 50-60% or more, **the 1:1 ratio would be sufficient for most crops**, particularly where only drought resistant and low fertility demanding crops would be suitable for areas where rainfall multiplier systems are likely to be selected (poor surface and texture soil conditions and low fertility are also limiting factors, not only water).

The ratio for external catchments is on the contrary larger, partly because of the runoff coefficient which may be low (25-40%) and partly because of the high water requirements for crops such as rice. Based upon the current experience, 1:10-1:30 ratios are recommended.

2.3 Biological Soil and Water Conservation Measures

2.3.1 Purpose, nature and objectives of biological soil and water conservation

Biological Soil Conservation can be defined as a set of conservation practices, which by the adequate cover of soil surface, the re-circulation of organic matter and nutrients as well as the establishment of vegetative barriers across the slope, prevent soil and moisture loss, improve soil properties and maintain/restore the productivity and stability of the agro-ecosystem.

In general, the practice of biological conservation is also defined as **conservation farming.** Biological conservation is also the backbone of concepts such as **land husbandry** (which do not exclude physical measures but rather integrate them within an improved land use and cropping system), i.e. a rational land use by the means of proper land and crop management practices able to improve the conditions of the soil for root and plant growth and moisture storage.

Conservationists have recently drawn their attention towards biological soil conservation which is thought to be ecologically sustainable and economically viable. It is also believed that the cost of soil conservation would be reduced and chances to succeed would be high. Several authors claim that if the principles of biological soil conservation are strictly followed and implemented, it would not be necessary to spend the considerable amount of resources and inputs that land reclamation and soil conservation, with sophisticated engineering works, normally require.

Since most of the biological conservation practices are linked to the normal agricultural practices it is also assumed that the concepts and principle for biological conservation would be easily understood and adopted by farmers.

However, **the introduction of better land and crop management practices is always a difficult task in degraded environments, particularly in dry zones.** As explained in several sections of the guideline, the vicious nutrient mining system in place in the Dry Zone is difficult to overcome by the means of biological measures alone because farming practices and other coping strategies, geared towards survival needs, do not leave much room for better land husbandry. The following few examples explain why biological conservation is a complex and challenging task:

- **The reduction of the woody biomass** because of deforestation force farmers to use most of their crop residues for fuel. Other residues are used for livestock or for small cottage industries such as jaggery production. It is clear that the introduction of biological measures such as dry mulching or stubble mulching is hampered by such constraints and thus of very limited or impossible application.
- **Soil erosion** reduce the most fertile part of the soil, particularly fine clays and organic matter, rendering the soil easily crusted after intensive rains, store less water and then produce limited biomass. This has implications on every biological measure meant to

be introduced (for instance less roughage for compost making, less residues to recycle in situ, etc.).

- The general decrease of crop productivity means also **less amount of animal feed production, less production of manure or compost and thus, less nutrients return to the soil.**
- The **worsening of soil surface** (crusts, low infiltration, etc.) and **profile conditions** (storage, aeration, exchange, etc.) **make vegetative barriers** difficult to be established and significantly decrease the efficiency of manure and fertilizers application.

In spite of these constraints, biological conservation measures are very important and considerable efforts should be spent to introduce and test them under different farming system conditions in view of a better approach for conservation and increased agriculture production. Wherever possible, biological measures must be integrated with physical structures and mutually benefit one from another. **Within the context of the Myanmar Dry Zone, there is ample scope to integrate most physical structures with vegetative measures, starting from boundaries and slowly progressing towards open fields if necessary. Similarly, a number of agronomic and soil management measures can be introduced to supplement physical barriers across the slope such as compost application, improved rotations, intercropping or ley cropping, improved fallow**, etc. Besides, interventions such as tree planting supported by water harvesting devices such as trenches on hillsides would trigger and encourage a consistent amount of grass and other plants to regenerate, which would be an entry point for several biological measures such as composting and mulching. **In this respect the integration between different land use and activities is an essential component of biological SWC.**

First and above all, **biological soil conservation prevents soil erosion by protecting the soil surface from the direct impact of raindrops.** Therefore, biological measures are effective mostly at the level of rainfall than of runoff. Rainfall is managed before causing damage to the land by the splashing effect of raindrops. The second principle is **the reduction of the time of water concentration and hence the reduction of both velocity and volume of overland flow.** Measures able to realize the first principle also hold for the second as vegetation disperses and offers resistance to the overland flow. The third principle rely on the increasing resistance of the soil against erosion because of the **increased stability of soil aggregates resulting from the increase of organic matter content.** Organic matter help the formation of elastic soil aggregates which absorb the kinetic energy of raindrops without being smashed. Moreover, soil aggregates that are rich in organic matter have more passages (pores) which enhance infiltration and thus water storage capacity.

In dry areas water is the major limiting factor for crop production and normally **plant yields are reduced more by a shortage or excess of soil moisture than they are by loss of soil.** Under these conditions, efficient use of limited water is of paramount importance. The aim is to capture the maximum amount of moisture in the soil and to hold it there as long as possible in order to support crop growth.

This can be realized by maximizing the moisture intake of the soil, prevent it from escaping and make the best possible use of it. **A wide range of farmland management and agronomic techniques are available for conservation and efficient use of limited**

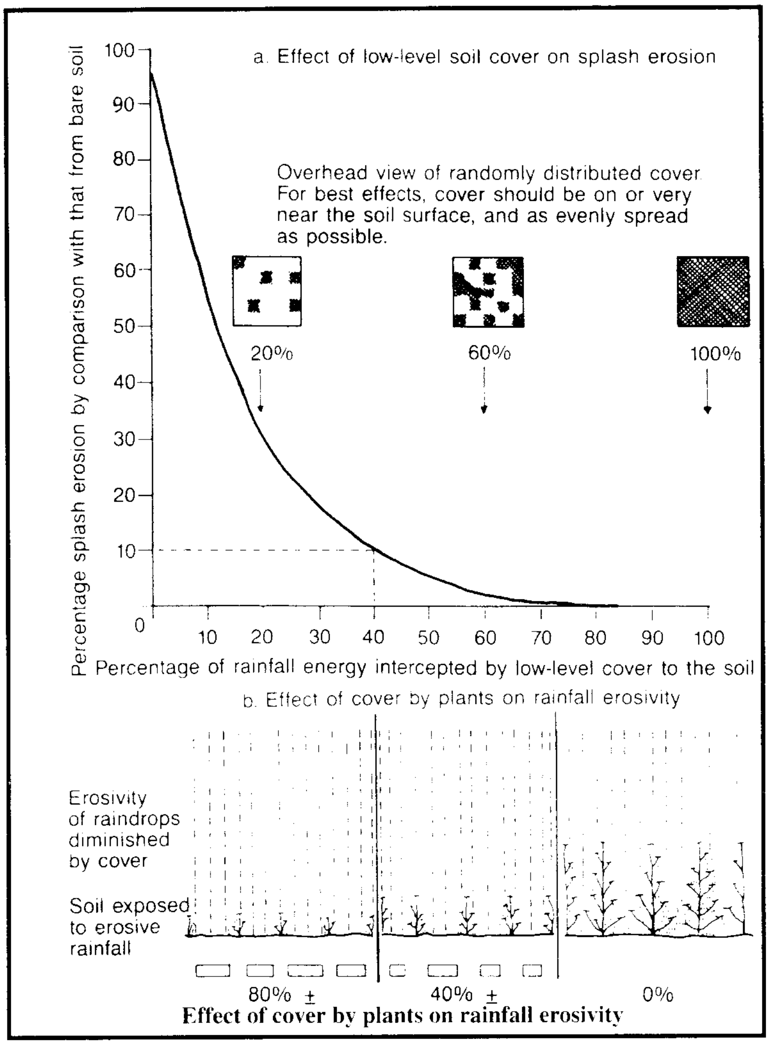


Figure 1 Effects of low-level cover in reducing splash erosion and rainfall erosivity.

moisture for successful crop production in dry lands. These techniques include the use of conservation tillage practices, improved fallows, appropriate plant population, selection of the right crop varieties, contour strips with drought resistant grass/ shrubs, use of crop residues, composting, etc... Other practices are also very important, such as the appropriate choice of crops and varieties, timing of planting in relation to moisture availability, spatial arrangement of plants, plant population in order to adjust moisture demands to the amount of moisture available in the soil.

The biological soil conservation measures listed in this guideline are not exhaustive and for most if not all of them, **experimentation and testing is required before advocating their suitability under Dry Zone conditions.** In on-farm demonstration sites or research stations, field technicians should test one or more of these techniques, alone or in combination with physical structures, and closely monitor performance over a period of several years before wide scale recommendations can be made.

Biological soil conservation measures are **divided into three major components (agronomic conservation, soil management and vegetative conservation)** based on the nature of application, materials used and management practices. Agroforestry is not included in this section and will be treated separately in section 2.5.3. However, agroforestry measures should be considered as biological conservation measures, where trees/shrubs are grown in different combinations and spatial arrangements together with crops.

Because most of the techniques described would benefit from the utilization of one or more conserving crops such as legumes and from the application of manure and compost, a brief explanation of the role and beneficial effects of Organic Matter and Nitrogen fixation on soil productivity and conservation is given below.

2.3.2 Organic matter (role and importance)

Organic matter or humus into the soil derives from the decomposition of plants and animals, through a multiple series of chemical transformations which depend from the interaction of factors such as the climate, microbial and other organisms activities, and soil properties (pH, type of clays, ions, etc.). The amount of organic matter into the soil would depend on the amount and type of litter (crop residue) produced by plants, and the provision of manure, compost, etc.

Organic matter, microscopic and macroscopic organisms (for instance fungal hyphae, earthworms and other invertebrates), detritus from fungi and animals, bacteria, biological exudates, all assist in stabilizing soil structure and thus its resistance against erosion agents. Large aggregates greater than 250 m diameter (macro-aggregates), are stabilized by inherent physical structure, wetting and drying cycles, and organic matter. Micro-aggregates (< 250 m are stabilized by live or dead fungi, invertebrates and micro-organisms (F AO Bull. No 72 - 1995).

Soil Organic Matter (OM) is the main factor in soil fertility. Organic matter improves the soil structure and thus enables the soil to resist erosion, hold more water without waterlogging, to remain moist for a longer time during dry spells and hold a greater reserve of plant nutrients. It helps to prevent the building up of soil acidity or alkalinity.

The addition of organic material to the soil in the form of manure and compost has a beneficial effect upon soil structure. The organic material change gradually into humus, a colloidal material which, together with the gums and hyphae of certain micro-organisms, bind soil particles into porous aggregates, and thus improve water and air movements. Organic matter contains also earthworms and other insects which burrow through the soil and further contribute to maintain a good infiltration capacity. Stickiness of the soil is also reduced making it easier to work. **Organic matter can absorb considerable amount of water, often 5 to 6 times its own weight.** Hence, the addition of organic material like compost to the soil will greatly increase the water retention in soils, holding up more in the crop root zone and allowing less to pass through into the subsoil layers. Likewise, it greatly reduces the rate of water evaporation into the atmosphere.

In case of heavy and erosive rainfall, soils rich in organic matter do not disaggregate easily and absorb more water, reducing runoff and erosion.

The level of soil organic matter can be restored or maintained through the application of manure (green and farmyard manure), compost and other organic residues like crop residues, etc. Moreover the need for organic matter maintenance can also be met through agronomic conservation measures.

Most of the green materials, farmyard manure and compost can release nutrients earlier than other organic materials, more resistant to decomposition (for example mulching of crop residues rich in lignin). In general, organic materials can be classified into three groups in terms of rate of decomposition. These are easily decomposable materials (eg. most succulent materials and herbaceous legumes like alfalfa, clovers and medics); intermediate (e.g. animal manures and some woody legumes like calliandra, soft compost) and resistant materials (e.g., hard crop residues, straw and stems).

Both of the organic materials (resistant and non resistant to decomposition) have their own advantages and disadvantages. The advantage of using materials resistant to decomposition is their long lasting effect on the organic matter content of the soil. The disadvantage is the removal of soil nutrients for their decomposition, at the expense of crops which require higher dose of fertilizer to offset the effect. Easily decomposable materials release substantial amount of nutrients for the immediate needs of plant growth and crop yield. However, such materials have little effect on the maintenance of the organic matter content of the soil.

The effects of organic matter on soil fertility and conservation are summarized in the following table (Source: Young 1989)

Primary effects	Consequences
Physical effects	
Binding of particles, root action leading to inproved structural stability, balance between fine, medium and large pores	Improved root penetration, erosion resistance and moisture properties; water-holding capacity, permeability, aeration
Chemical effects	
Nutrient source, balanced supply, not subject to leaching, with slow, prtly controlleable, release	Including better response to fertilizers, non-acidifying source of N, mineralization of P in available forms
Complexing and enhanced availablility of micronutrients	
Increased cation exchange	Better retention of fertilizer nutrients
Improved availability of P through blocking of fixaton sites	
Biological effects	
Provision of a favourable environment for N fixation	
Enhanced faunal activity	

The proportion of animal manure or farm yard manure applied to the fields and the management of crop residues is extremely variable in dry zones, from almost no recycling and application of manure to intensive manuring and skillful handling of crop residues. This depends from the cropping system, the type of soil, the level of degradation and social factors interacting in a given area.

As mentioned earlier in this guideline, a situation characterized by continuous mining or removal of residues for consumptive purposes, limited biomass production of pastures, steady decrease of manure applications, shortening of rotations and countless other practices typical of degraded environments, would be conducive to the collapse of soil stability (see figure 2), decreased fertility, accelerated erosion, desertification and poverty. Besides, in semi-arid areas high temperatures lead to a very rapid mineralization of the organic matter; this situation is more serious on cultivated lands as excessive cultivation enhances organic matter breakdown. Biological Soil Conservation in arid and semi arid environments should then take into account such constraints and develop appropriate packages for improved farming or land husbandry accordingly.

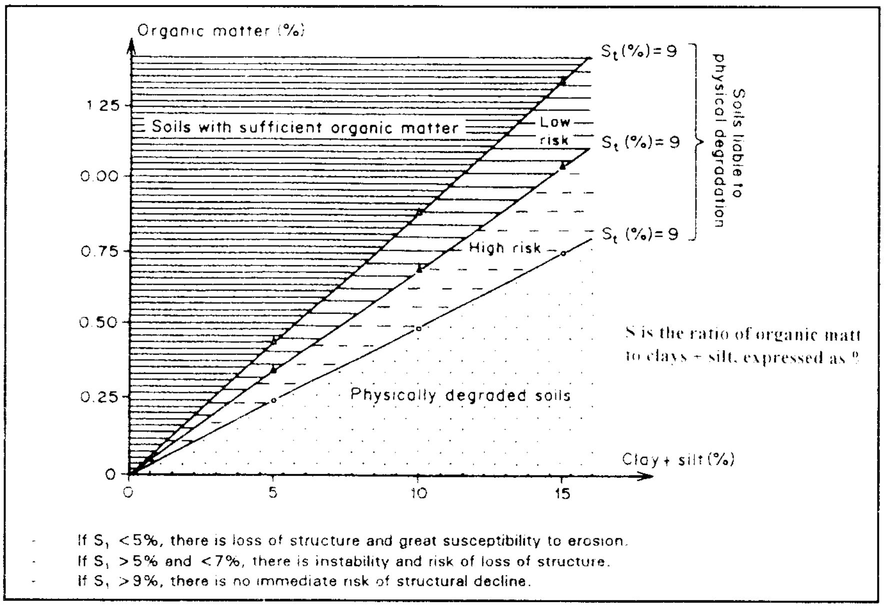


Figure 2 Critical organic matter levels for maintenance of physical stability (proposed by Pieri, 1992)

2.3.3 Biological Nitrogen Fixation (BNF)

Cropping in dryland regions need nitrogen to be economically successful (Keating et al. 1991). One source of nitrogen is from organic matter which is gradually released through its chemical (increased cation exchange) and biological activity. Another important source is the Biological nitrogen fixation which takes place in the soil through symbiotic, and non-symbiotic relation.

Non symbiotic fixation is carried out by free living soil organisms (Azotobacter and Azospirillum) which can contribute to reduce the nitrogen requirements of cereals and non-legume crops by 20 kg/ha. It can be of substantial importance relative to the modest requirements of natural ecosystems, but small in relation to the greater demands of agricultural systems.

Symbiotic fixation occurs through the association of plant roots with nitrogen fixing bacteria. This can reach very high levels of nitrogen fixation (up to 500 Kg/ha) depending on the type of legumes and soils, and would play a major role in the improvement of soil fertility and structure. Many legumes are associated with Bradyrhizobium and Rhizobium, while a few non-leguminous species are associated with Frankia. The latter are also accountable for N-fixations up to 60 kg/ha.

Also important for BNF are various groups of fungi and algae living in association with plant roots. One group, vesicular arbuscular micorrhizal (VAM fungi) forming both vesicles and arbuscules (knot-like structure) on the surface and within the root (FAO- Bull. No 72) facilitate the uptake of nutrients in poor soils (Phosphorus) and colonize earthworms and other insects.

Nitrogen fixing bacteria-legume association: The Rhizobium-legume symbiosis is seen as a beneficial giving-taking system, the legume supplying sugars to the rhizobium localized in the nodules along the root system, while the Rhizobium in turn supplying fixed nitrogen to the host. Nitrogen fixation allows legume crops to be considered as conserving crops, particularly when their root system and parts of their vegetation is returned to the soil.

The importance of legumes has been since long recognized by farmers and conservationists, either as a productive crop (e.g. pulses, etc.), or as a green manure crop (e.g. Stylosanthes spp, Centrosema pubescens, etc.), including mixed stands with grass, alone as legume leys, or as a cover crop in perennial plantations (eg. Pueraria phaseoloides). In an improved cropping systems it is usually recommended to use legumes in rotation with non-legume crops. Among the known plant-bacteria associations, the legume symbiosis is the best known and deserves a first place amongst the present opportunities for increasing crop yields. Nitrogen fixation by legumes provides a cheap form of readily available nitrogen.

Legume root nodule bacteria are widely distributed as a result of the natural distribution of legumes and cultivation of leguminous crops. Despite this fact, it was found that many soils are devoid of the particular strains of Rhizobia able to nodulate effectively crop or pasture legumes introduced to other continents, regions or virgin soils (for instance soybeans). Differently, other studies indicate that newly introduced species like Siratro (*Macroptilium* atropurpureum) and Grams may nodulate effectively native strains of Rhizobia and in such situations the need to inoculate the grams and siratro is questionable.

Inoculation is important in soils in which the specific Rhizobia are absent or sparse, in soils that have low organic matter and where indigenous Rhizobia are ineffective, and where host legumes has been absent from the area for some time. It is indicated that cowpea, mungbean and pigeon peas generally do not appear to require inoculation. On the contrary soybeans and chickpeas are more specific on their Rhizobium requirements.

Among the solutions being advocated to arrest the declining productivity of cropping lands are the introduction of legumes into cropping systems. There are a number of studies that show the different legumes capacity of fixing substantial amount of nitrogen every year. For example, it is demonstrated that Peanut could fix 123 kg of N/ha, cowpea 269 Kg, Townsville stylo 220 Kg and Leucaena leucocephala up to 575 kg of N per ha per year.

Mycorrhizal association: Several plants growing in soils with an high content of organic matter form mycorrhizal associations with micro-fungi and their hyphae or mycelia. In such situations many shrubs, trees and crops have been shown to form mycorrhizal. The fungal hyphae contain significant levels of nitrogen in the form of proteins which are digested by the plant roots. Mycorrhizal associations has been found in banana, cocoa, coconut, coffee, cotton, rubber, sugarcane and tea plantations. Of particular interest is the VAM found in many soils mentioned above, which facilitate the uptake of nutrients such as phosporus from soils low in that element. It is ascertained that inoculation of soils with VAM help increased uptake of nutrients such as P, S, Cu, etc., and improve both plant growth and resistance to drought and pests of some crops (wheat). It has also been assessed that tillage reduces the frequency of VAM and reduces the population of earthworms 10-30-fold, both killing them and destroying their burrows (Brust et al. 1986).

2.3.4 Agronomic conservation measures

Excessive soil loss by the splashing effect of rainfall and runoff occurs mainly under two conditions. **Firstly, when the existing vegetation does not provide complete ground**

cover. Secondly, when the ground is devoid of vegetation during critical periods of the year, particularly at the beginning of the rainy season.

Agronomic conservation measures designed to counteract these events are: Strip cropping, Ley cropping, Cover/green manure crops, Inter-cropping, Relay/Double cropping, Crop rotations, Stubble mulching/crop residue management, Contour cultivation and planting, Improved fallows, Improve plant population density, Multiple cropping, Rows arrangement/ configuration, Compost making and Improved use of fertilizers.

The above mentioned measures are described in detail at the end of this section. Most of the specifications are only indicative and may be modified or adjusted to meet the existing cropping patterns and farming practices.

2.3.5 Soil management practices

Cultivation practices: These practices include farm operations that would improve the moisture retention capacity of the soil, control erosion and hence improve yields. Most of these measures are integrated with physical structures for soil and water conservation. The ones applicable under current conditions in the Dry zone are contour ploughing and planting. Others such as deep tillage and tie-ridging have already been treated in the above section for physical structures.

Fertility improvement practices: They include all practices aimed to increase the amount and quality of organic matter content into the soil by improving the transformation of plant and animal residues. Under Myanmar Dry Zone conditions, only compost making and efficient use of fertilizer applications would be treated.

2.3.6 Vegetative conservation measures

Vegetative conservation measures are those measures applied to potential lands to maintain their productivity or to degraded lands to restore productivity. In other terms they are considered curative when applied to degraded lands and preventive when applied to potential lands. These measures use predominantly trees, shrubs and herbaceous grass and legumes planted in different combinations or in pure stands for different purposes.

Vegetative measures aim at controlling runoff through vegetative barriers, stabilize structures or farm boundaries, revegetate forests and grazing lands affected by insufficient ground cover, and stabilize degraded and fragile lands, including gullies. These measures are also intended to produce substantial amount of biomass for multipurpose uses and thus increase the general productivity of the land.

B. GRAZING LAND

2.4 Soil and Water Conservation Measures for Grazing Land

2.4.1 Objectives and potentials

In the Dry Zone, **grazing lands are mostly those lands which have lost their potential for crop production, bush lands, scattered forest lands or marginal lands affected by various levels of land degradation.** In some cases, the latter are also called bad lands or waste lands when erosion forms such as gullies or bare rocks, poor truncated soils and crusted layers appear over large areas. Besides the differences in terminology, the amount of grass is limited to few species which are extensively grazed. The fact that in some villages there are vast portions of hillsides available for grazing does not eliminate the problem of overgrazing or the unsuitability of most of those sites for grazing and trampling by animals.

Free grazing on the above areas is mainly undertaken by small ruminants such as sheep and goats and to some extent by cattle. However, draught cattle are mostly fed by sorghum stocks and, to a minor extent, by millet stocks. Pigs are fed in the homesteads with a mixture of kitchen waste, tamarind seeds, boiled sorghum seeds, rice bran and ground nut cakes. The number of draught cattle is reported as insufficient by many households because of scarcity of feed, and the other animals are kept within a limited number as per the quantity and quality of forage pastures. **The whole situation is the reflection of the existing levels of environmental deterioration and accelerated depletion of natural resources.** The poorer the soils and their water holding capacity the less biomass they produce. This subject has been amply discussed in Part I of this guideline, i.e. the cycle of land degradation - decreased production and its effects, and would not be repeated here. Rather, this section is intended to emphasize on a few strategies and techniques able to enhance and support the growth of vegetation for livestock use and the rehabilitation of marginal areas for forage production.

In the whole Dry Zone there are numerous areas that can be improved for pasture development or fodder crop production by the introduction of SWC measures. Some of these measures would be focusing on forage production only but some are integrated with other activities, for instance forestry. Here again is evident how important integration with other sectors is and what sort of implications a given measure may have on alleviating or solving different problems. In the section for the cultivated land we have seen how much some physical and biological measures would be important to enhance grass and fodder crop production.

The different soil and water conservation measures suited for grazing land are described in detail at the end of this section. The measures are meant to increase forage production and improve existing pastures with simple management techniques. Other measures, more pertinent to elaborated control grazing practices, pasture improvements and intensive forage production are beyond the scope of this guideline and should be treated separately.

2.4.2 Strategies and prerequisites for SWC for grazing lands

Strategy 1: areas with limited and erratic rainfall, having gentle slopes (< 5%), low fertility/ shallow soils, mostly abandoned lands or used for temporary grazing. These are areas located:

1. near eroded cultivated fields but unable to sustain crops;
2. adjacent to main gullies: the land is severely eroded, with truncated soils or incised by deep rills, with crusts, low permeability, coarse or heavy texture, etc. Some of these areas are suitable only for planting multipurpose trees but there may be spots with gentle slopes that can be rehabilitated with SWC measures.
3. top of small plateaus in several portions of the bad lands such as the gentle or almost flat tops of severely degraded hillsides in Magway township.

› **Application of rainfall multiplier systems for forage production, sylvipasture systems, control grazing and area closure.**

Strategy 2: areas with severe gully erosion

1. Revegetation of gullies
2. Stabilization of checkdams

› **Application of gully control measures, reshaping, checking, planting multipurpose species and area closure.**

Strategy 3: areas under long fallow and cultivated lands for forage crops

› **Application of rainfall multiplier systems for forage production if slope < 5%. For slope >5% apply biological measures and bunds for maximum water retention capacity + control grazing (see SWC measures for cultivated land).**

Strategy 4: bush lands or scattered forest areas with steep slopes, severe erosion, shallow soils.

› **Application of rainfall multiplier systems for forestry, control grazing and area closure.**

Strategy 5: areas around the homesteads

› **private pastures, intense forage production, multi-layer gardening, etc.**

Strategy 6: cultivated areas used for forage crops (normal soils, slopes < 30%)

› **different physical and biological SWC measures (see section 1 for the cultivated land).**

Measures for strategy 1 and 3 would be elaborated in this section. The remaining strategies are mostly covered by other sections of this guideline as per the nature and main purpose the different SWC are selected for. For instance, the main purpose of trenches is to support the growth of trees but may also significantly contribute to the regeneration of natural grasses and be stabilized with improved pasture grass or legume seeds. However, being their main purpose the enhancement of tree growing, they are classified under the forestry section. In this respect, most of the measures that are explained in the other sections are integrated with the livestock sector because they contribute to increase animal feed.

Measures for Strategy 2 are explained in the section for gully control.

Strategy 4 would be addressed when explaining SWC measures for forestry.

Strategy 5 is regarded as a set of activities aimed at increasing forage production by intensive management of the plots, i.e. sowing of improved grass, legume and, eventually other shrub/tree multipurpose species, composting and fertilization. Most of the measures to apply here are similar to those explained in the section for biological measures, the only difference being the type and purpose of the forage crops or pastures to grow/improve in this particular case.

Strategy 6 include all possible measures described for the cultivated land but aimed at increasing forage production. For instance when the crops are forage crops such as Sorghum. They also include all other agronomic measures which are enhancing the production of forage (ley cropping, etc.).

The rehabilitation of rangelands (waste lands), improvement of marginal areas and any other land extensively overgrazed should be decided together with the intended beneficiaries.

These aspects are crucial because most of those lands do not have defined ownership, are usually managed communally and would not be a top priority within the range of farmers desired interventions. Nevertheless, demonstrations and trials at small scale first may convince several of them to provide the necessary effort to rehabilitate such degraded areas. Use rights over the particular area intended to be reclaimed should be discussed in an assembly meeting and see whether the majority of farmers agree not to interfere with the trial, ensure its protection (guarding, fines to eventual abusers, etc.) and follow the management practices suggested by the technician.

An important aspect to be discussed is the free movement of animals, that should not enter into the protected forage producing areas. If large areas are closed for pasture regeneration (see area closure) there should be a signed agreement by all farmers of the community to guard the area, by adopting a turn system or by appointing a site guard whose functions would be to keep animals away from the area. There should be alternative sources of fodder supply to the villagers, i.e. other areas to graze or cut and carry. Otherwise, the regeneration of one area will be at the expense of other areas under more pressure and degradation.

2.4.3 Group formation

Rainfall multiplier systems may be applied in both communal areas or in private holdings not used anymore for cultivation because of severe degradation or/and low fertility. For the communal lands, the whole community should agree on the activity whereas a target group of interested farmers could be dealt with in the second case. In case of private holdings consensus is normally reached rapidly and clearly whilst for communal assets some villagers may be reluctant and several meetings are normally required. Some farmers may think that the measure may disrupt their usual way of doing things, perhaps forcing them to spend extra time or labour to keep the animals away from the treated area or look for remotest places where to graze their animals. In most cases they are partially right since nothing is done at a zero price but then it is important to balance the advantages and disadvantages and see whether the measure is applicable or not. Rational and practical decisions can be made only when the purpose and the technicalities of the measure, including its costs and management aspects, are clearly explained to the farmers/livestock owners/herders.

Area closure can take place in small areas or in large portions of the hillsides. The long term nature of this activity imply that strong and binding solidarity mechanisms and share of responsibilities should be in place and accepted by all. Tenure and grazing issues are the major element for the success or failure of this particular activity.

Nevertheless, based upon the different activities, the concerned groups should be formed, elect a committee or a team leader (depending from group size and measures involved) responsible for the overall implementation and management aspects, setup rules and regulations, sign contract between group members and the supporting institution or, in absence of external support, between the group members themselves.

2.4.4 Types of measures

The measures described in detail should be proven in the field before the wider application in the Dry Zone. However, it is believed that in their current design or modified they may be the key for rehabilitating marginal and degraded lands into productive pastures and grazing areas.

The practices suggested here have the precondition of control grazing arrangements, to be made with the farmers or the livestock owners before implementation takes place.

Control grazing is necessary to avoid trampling on the structures and damage to the forage crops, especially at the establishment stage. The possible control grazing practices applicable in dry areas are the cut and carry system, grazing rotation and control of the number of animals per unit of area grazed (based on local conditions, i.e. soils, rainfall and type of grasses and regeneration).

Small ruminants are drought resistant and viewed by farmers as an asset able to improve their food security during drought periods. The fodder supply and availability of pasture is a main concern for such farmers. Then, measures able to increase the quantity of fodder produced per unit of grazing land or by increasing the area of pasture lands will be of great interest.

Following the same participatory approach stated in the introduction, measures have to be selected together with farmers prior to implementation. Farmers should be aware about the negative (increased labour, etc.) and positive (increased fodder) implications that a given activity can generate and their final commitment should be obtained.

2.4.5 Important grasses and legumes

A short list of exogenous grasses and legumes suitable for semi-arid areas is given at the end of the guideline (Annex 4). It is also recommended to refer to local experience, research data, publications and field documents prepared specifically on this subject. Before any wider application in the field, it is recommended to try out a given measure using different plant species at small scale. Testing and comparison of findings are required before final selection and wider dissemination of suitable packages. **Other native grass of particular interest for the Dry Zone are listed and briefly described in the section dealing with stabilization of physical structures** (see page 271).

For each of the exogenous grass and forage legumes species given in Annex 4, a summarized description of their characteristics would include rainfall requirements, soil type, **suitability for hay, palatability, tolerance to drought and salinity, sowing rate, dormancy factors, seed treatment, land preparation for establishment and other relevant information depending on their value and potential for use in then Dry Zone.**

C. FOREST LAND

2.5 Soil and Water Conservation Measures for Forest Land

2.5.1 The important of trees in arid and semi-arid areas

Before starting the description of the recommended measures it is essential to underline the importance and function of trees in dry areas:

- They can act as a **soil stabilizer** and prevent water and soil erosion.
- They are an important **source of fodder** for livestock and wildlife at a time when herbaceous fodder is not available. A number of multipurpose trees and shrubs are ideal for protecting and improving the soil.
- They are a **source of wood products**, including fuelwood, poles, and timber.
- Fuelwood is almost the only **source of domestic fuel**, not only in the rural areas but in some urbanized areas as well.. Wood is also used as a construction material.
- They are a **source of foodstuff** for the population. Many fruits, leaves, young shoots, and roots provide valuable food in the dry season and, therefore, comprise an important reserve during emergencies.
- They are a **source of non woody products**. Many trees and shrubs yield products which are important for everyday use by the inhabitants, for industry, and at times, for export. For example, a variety of tree and shrub species are characterized by a high content of tannin (utilized by the leather industry) in their bark or fruit. Other trees and shrubs yield fibers, dyes, gums and pharmaceuticals. The pollen of many trees and shrubs is used for honey production (beekeeping).

Development programmes in arid and semi-arid regions should include a forestry component. This component should not be seen separately but must be integrated with agriculture and animal husbandry to optimize land use.

Fuelwood: Forest plantations in arid and semi-arid zones are often proposed for the production of fuelwood. The production of fuelwood can be crucial to people, because over 50 percent of the wood removed from the world s forests is used for fuel and 90 percent of the inhabitants of developing countries rely on it for their domestic needs; these people simply cannot afford other sources of energy. Fuelwood is also a marketable commodity that is transported over long distances. Fuelwood accounts for 70-80% of South-Asia total energy use.

Demands for fuelwood and charcoal are increasing, and wood is likely to continue to be an important source of domestic fuel and timber for small-scale industrial use in rural and urban areas. Most of the fuelwood still comes from natural forests and woodlands that are being cut down and destroyed at alarming rates.

Scarcity of fuelwood can create further problems. **People frequently turn to the next available fuel, such as agricultural residues and dung**, instead of using these materials to maintain the soil fertility of agricultural land. Besides, scarcity of fuelwood affects rural families and their life, as more time must be spent in fuel gathering at the expense of more productive work.

Fodder: A significant role of woody vegetation in arid zones is its contribution to a pastoral economy by providing arboreal fodder. In this context, in Africa the Acacia Albida tree is particularly noteworthy among the tree species for its contribution to animal feed. A stand of 60 trees/ha of Acacia Albida is estimated to yield some 400 to 600 kg of edible pods. In the Dry Zone of Myanmar, although not productive as Albida, this role is occupied by Acacia Catechyu which is valued for its hard wood, good coppicing capacity, production of substantial amount of foliage and pods (used by goats), and gum.

The role of the woody vegetation in fodder production can be examined in three situations:

- **Normal scarcity situations**: during the dry season (when grass and forb vegetation is not available), only trees and shrubs can provide the necessary feed for livestock; this is a traditional use of the woody vegetation in arid regions. When such vegetation is not available, the production of livestock can be seriously affected, as people do not normally have the resources to acquire other types of feed for their animals. The creation of fodder resources for scarcity situation is, therefore, a vital activity for maintaining the production of animals.
- **Emergency situations**: rainfall in arid and semi-arid zones is not only variable during the year but there is also a considerable variation between years and, at times, extended periods of drought. Under this situation, trees and shrubs assume greater importance in the form of emergency fodder reserves for livestock, since ligneous vegetation is better able to survive extended periods of drought than annual plants.
- **Contribution to the feed budget**: The most intensive method of fodder production may be the creation of year-long forage plantations on convenient sites to improve animal production. Forage species can be grown in pure stands, harvested in a controlled way, and then fed to livestock. Where grasses are grown, livestock could be moved between the different areas of production to enable optimal use of both types of forage.

Improvement in Agricultural Production:

Protection against wind erosion. In most arid and semi-arid zones wind erosion is a serious problem. The destruction of the vegetative cover exposes the soil to the desiccating effects of hot, dry winds, resulting in dust storms, etc. (see section on wind erosion). Such damage can be diminished by the establishment of windbreaks and shelterbelts.

Protection against water erosion. During heavy storms roads are damaged, lowlands are flooded, and streams are filled with muddy water. The loss of water through runoff and the ensuing soil erosion can be controlled by vegetation which improve soil fertility, reduce runoff, avoid the siltation of dams, regulate stream flows and prevent floods. In the Dry Zone, most of the forestry activities would be geared towards protecting and treating steep slopes, often characterized by shallow and depleted soils. The runoff/erosion control ensured by the woodlot would be utmost beneficial on downstream cultivated fields, but also on SS dams in gullies which will be protected from destructive water flows.

Increase soil fertility. Agricultural production in dry zones is frequently hindered by poor soil fertility. However, the importance of soil fertility is often overlooked; water shortage is considered the principal constraint. Whereas the conventional method to improve soil fertility commonly consists of repeated application of mineral fertilizers, this problem may also be solved through the systematic use of soil-improving tree species (see agroforestry systems).

2.5.2 *Place of trees and shrubs in rural landscapes*

To grow trees or shrubs (in any form) is a forestry practice; forestry, in turn, is a land use exercise. Pressure on land for agriculture is high in arid zones, so high that land unsuitable for agriculture is sometimes used in a desperate effort to grow agricultural crops . As a result, forestry can be relegated to lands which are too poor for plant growth.

There are several ways to plant trees and shrubs in the rural landscape, including:

1. Trees in rows (windbreaks and shelterbelts) to protect crops and pastures against wind and desiccation.
2. Trees intermingled with agricultural crops to protect the crops and to reconstitute and enrich the soil (Agroforestry).
3. Trees and shrubs grown during the fallow period to enrich the soil, and to provide fuel, fodder, and secondary forest products.
4. Linear plantations along roads and waterways to protect infrastructure and adjacent fields, and to provide shade and contribute to the production of fuelwood, fodder and non-woody products.
5. Woodlots established under rainfed or irrigated conditions to make the best use of unused land, and to contribute to needed wood supplies.
6. Intensive management and enrichment of natural forests and woodlands to maintain a stable environment and yield essential products traditionally used by the local population.

Within the above, it is possible to select the most appropriate combination of land use to:

- Improve agricultural and livestock production.
- Stabilize and enrich the environment.
- Meet essential needs for fuelwood, farm timber and non-wood products for the rural population.

2.5.3 *Combined production systems*

Agriculture, livestock production, and forestry can be practiced in rotation, simultaneously, or spatially on the same piece of land. **Agroforestry** aims to ensure ecological stability and to maximize benefits to the user of the land. Agroforestry can be **agrosylviculture** (where agricultural crops and forest products are grown simultaneously or sequentially), **sylvipasture** (in which forest products and livestock are grown), and **agrosylvipasture** (where food is grown for humans, domestic livestock graze, and woody vegetation provides wood products for humans and fodder for animals).

2.5.4 *Private and community forestry*

This section emphasizes on the differences in approach and purpose of establishing private or communal woodlots and other form of plantations. Whereas private forestry is an activity that requires the commitment of single individuals alone or in small groups, community forestry requires a wider perception and consensus from most if not all community members and thus a **clear understanding and responsible agreement on the scope, mode of implementation and management aspects of the tree woodlot intended to be established.** Experience in community forestry is markedly illustrated by frustrating failures throughout the world. On the contrary, private forestry is relatively successful provided selection of species and planting techniques are appropriate.

F-

The reasons of failure of community woodlots reside mainly on tenure factors, poor participation, selection of unsuitable species, poor planting techniques and management aspects. The technical side being important, it is often not the main cause for failure.

Most rehabilitation exercises in the form of communal plantations have been planned by foresters with the best of intentions of protecting catchments, control erosion and establish a forest which should not be used for a number of years, perhaps decades. They often neglect that communal lands are currently used for grazing and/or the collection of branches for livestock and domestic uses. Community members may have difficulties to shift to another area unless convincing arguments on the foreseeable increase of productivity of the area under woodlot would be sufficiently attractive to make them agree on the set of measures and management aspects required to reach that scope.

There should be agreements on the tenure issues and settling of pending problems such as:

- Are other areas available for grazing and for the collection of woody materials? If yes, are they accessible? If not, what alternatives do we have? Should we reduce then the area for woodlot plantation?
- Who owns/uses the land? The State, the village, some individuals? If the land belongs to the State, how to ensure that the community woodlot would be used by the community? Are forms of lease or transfer of title arrangements possible? If yes, what type of procedures? Are they lengthy? Is there a price? If the land is owned by individuals, would they donate it to the community? Are compensations needed? What kind?
- How to ensure control grazing? Is site guarding possible? By whom? By single individuals or in shift? For how long the area is to be closed? Is cut and carry of grass possible? After how many months or years?
- Who is going to participate in the construction of conservation measures? Would they be the direct beneficiaries or would they simply carry out the work? How to organize the group of laborers? What type of training they need? What tools are required? When to start the job? What species should be planted and why? When and how to plant trees? What are the additional management requirements (pruning, weeding, mulching, etc.)? When trees/branches can be harvested and how to do it? How to share the products?
- What type of contracts are needed? Is payment envisaged for the establishment of the woodlot? If yes, what are the norms, the mode of payment and what type of control mechanisms should be in place? Who is responsible for the overall management of the woodlot?
- What type of disciplinary measures should be adopted to avoid interference (fines, exclusion from benefits, others)? Would they be enforced? By whom?
- What type of assistance is required from the Forestry Department? For technical assistance or for the formulation of lease agreements, or both? How often foresters should visit the village? What training they should provide to the farmers?

These questions are only but a few of the numerous issues that should be clarified and agreed by all before starting a forestry activity, particularly in communal lands.

2.5.5 *Group formation and agreements*

Similarly to the measures described for the other land uses, group formation is an important step in the procedure for woodlot establishment in particular and other forestry activities in general. Group formation can be undertaken in different ways. However, the following recommendations should be considered:

A group should be homogenous in terms of interests, motivation and commitment. Members should all agree on why, what. how, where and when to do things. Most of the questions mentioned above should be answered and a clear action plan decided jointly with the forester should be endorsed by all members.

Group members may have the same interest but have different skills in planting and management. This weakness can be resolved through training and field visits from forester or trained villagers.

The group should sign a contract where responsibilities and assignments are clearly specified for every member. This contract may be endorsed by village leadership and countersigned by the forester. The contract may include lease or title of ownership transfers by the Forestry Department and procedures for implementation. In this case, a proper documentation should be attached, including the map of the woodlot and terms of lease.

Large groups may need to split into smaller groups and appoint team leaders. In case of conservation works, a clear division of labour is required, with some members responsible for the layout and marking of the structures while others for their construction. Training and supervision of these groups is an important and continuous task that foresters should ensure.

Small groups or individuals should be organized independently and checked regularly by the forester. These groups or individuals may meet regularly and share views and experience.

If payments for conservation and/or planting are envisaged, mode of payment, work norms, criteria for eligibility, disbursement periods, record keeping, etc., should be specified and agreed by group members.

If guarding is required, the group would decide on the mode of guarding (rotation or appointment of site guard) and ensure that protection is agreed by the rest of the community.

In case the group is the community itself, there should be sub-groups in charge of the different activities. One group may be responsible for construction and planting of structures alone. Another group for guarding, for weeding, etc.

Frequent management meetings, possibly in presence of the forester, should be held to verify the correct performance of the different activities and solve problems.

2.5.6 *Selection of soil and water conservation measures*

Selection criteria: Most of the SWC measures for forestry presented in this guideline would focus on methods able to increase water availability to plants and thus on rainfall multiplier systems.

The selection of the measures should be tailored around the type of tree species to be planted and their water/soil requirements, the type of soils and topography, and land users needs.

Design: Physical SWC measures for reforestation purposes should have a proper dimension to accommodate peak runoff discharges, layout must be done very accurately because single errors may have a multiplier effect downstream.

Biological measures such as agroforestry and soil management practices should be also planned carefully, paying attention to spatial arrangements, utilization of biomass and management techniques.

Integration between land uses: As mentioned in several parts of the guideline, dry zone forestry is integral part and often the precondition for the successful treatment and rehabilitation of cultivated lands. This naturally happens because forest land is most of the time geographically confined on the upper reaches of watersheds, i.e. hillsides, mountains, ridges and plateaus. Therefore, most if the interventions aimed to improve cultivated lands should either be preceded by or be undertaken contemporaneously with forestry activities. A possible exception would be the diversion of excess runoff from the hillsides by the means of cutoff drains.

However, the rehabilitation of degraded hillsides and poorly managed forest areas should be seen as an opportunity to protect the environment as well as to raise incomes and reduce the over-exploitation of already scarce natural resources. Within this context, the concept of UTEs retains its full importance as a means to ensure an integrated and sustainable development of a given territorial unit (see page 110).

Integration between activities: Integration between physical and biological measures is essential for the successful growth of seedlings. In this respect, the involvement of agronomists and livestock specialists is likely to be important. In the following pages, many examples would be given in this respect.

Establishment/construction: As specified in other parts of the guideline, the construction should start from the top of the catchment and move downwards. In case of physical structures, the dimensions and construction standards should be outstanding and without gaps. Planting should be timely done and great care in transporting seedlings from the nursery to the plantation site should be ensured (10% of woodlot failure is due to poor handling of seedlings). Manuring and mulching of planting devices (pit, trench, etc.) should be ensured. Agroforestry measures should pay great attention to site preparation, layout, handling of seedlings, fertilization/manuring, management of trees, etc.

Management and maintenance: Each woodlot would need a number of management operations such as weeding and mulching of grasses, pruning, pollarding and coppicing, etc.

The maintenance of physical structures would include the repair of breakage, stabilization of embankments and de-siltation of collection trenches/pits if deposition is too high (intensive shower), gap filling and reinforcements with stones if necessary.

DETAILED DESCRIPTION OF MEASURES

PHYSICAL CONSERVATION MEASURES ON CULTIVATED LAND

A. MAXIMUM WATER RETENTION

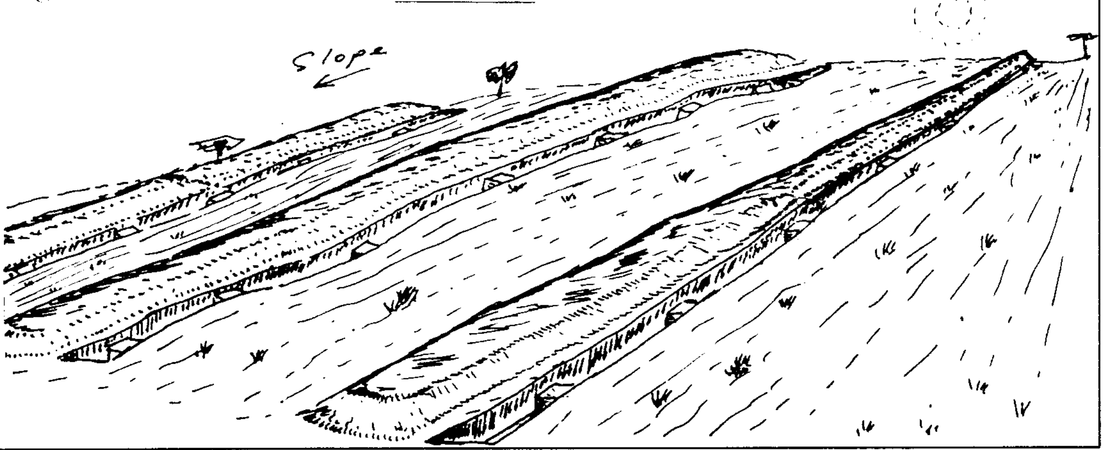
LEVEL SOIL BUNDS

Definition and scope

A level soil bund is **an embankment constructed along the contour (points of the same elevation), made of soil, with a collection channel or basin at its upper side.** Soil which is eroded between two bunds is deposited in the basin behind the lower bunds. Whenever the basin is full of sediment, the bund should be raised. In this way, a bench terrace will develop in the course of years (3-7 years based on slopes and type of soils).

The bund reduces and stops the velocity of runoff and consequently reduces soil erosion and the steady decline in crop yields. They are impermeable structures, unless provided with spillways, intended to retain all rainfall, and hence, contributing to increase the moisture retention capacity of the soil profile, water availability to plants, and increase the efficiency of fertilizer application if any. In terms of increased productivity, the water retention effect alone can give increases in crop yields of up to 50%, and even more, particularly in drier areas. Through their water retention effect, the bunds may allow some crop yield even in drought years.

Figure 3 Soil bunds



Technical specification

Slope range: Soil bunds are suitable within a 3-30% slope range. However, in dry zones, above 5-10% slopes and soils with limited infiltration capacity (crusted, shallow, etc.) it is recommended to provide soil bunds with spillways (checkdam-spillway, lateral spillways, revegetated outlets, etc.). For higher slopes, stone bunds or bench terraces are preferred.

Type of soils: soil texture and soil depth influence the design and construction of soil bunds. The first involves their spacing apart and need to apply excess water disposal devices. Where soils have a loose texture and high infiltration rate the bunds may be spaced further apart than those on heavy soils with low infiltration. However, loose texture is not easy to compact and thus, bunds should be of bigger dimensions. In heavy soils, some temporary waterlogging problems may affect the crops. In this case, spillways are needed to evacuate excess water (see section on spillways for soil bunds below). **A knowledge of the soil depth is required as the vertical interval between the bunds should not exceed twice the top soil depth.** If this is exceeded then the resulting terrace will be partly exposed to the subsoil.

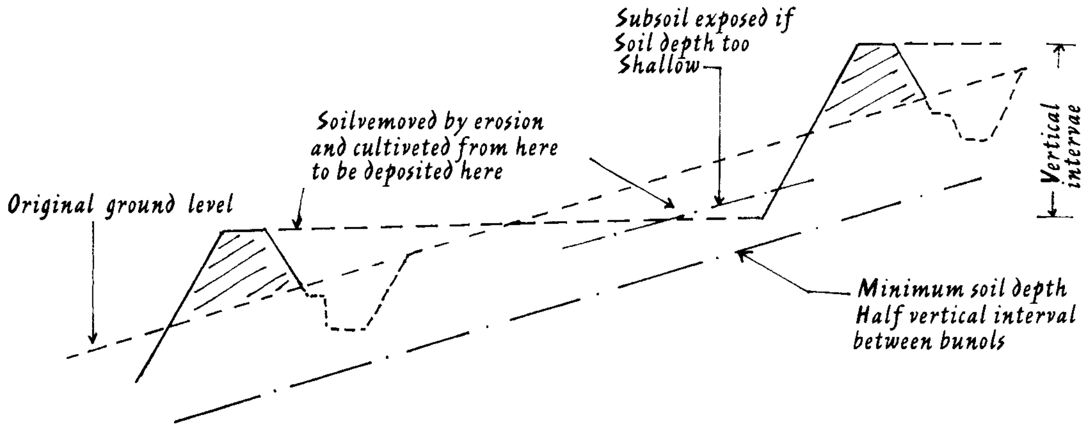


Figure 4 Minimum Soil Depth Requirements

Spacing apart soil bunds: There are formulae to construct soil bunds.

1. Ramser equation: Vertical interval (VI) = $0.305 \times (a + \frac{S\%}{b})$

   where a = 2 and b ranges from 2 to 4 if climate is aggressive (take 3 as average)
   For instance in 9% slope VI = 0.305 x (2 + 9/3) = 1.5 approx.

2. Then apply the formula for Slope% = $\frac{\text{Vertical Interval (cm)}}{\text{Horizontal distance (meters)}}$

   Thus, horizontal distance between bunds = 9 x 1.5 = 13.5 meters (40 feet approx.)

3. Fix standard VI for each range of slopes

   Slope 3-8% => VI = 1.5-1.2 m

   Slope 8-15% => VI = 1 m

   Slope 15-30% => VI = 0.8-1m

   This procedure is to be supplemented by the determination of soil depth and soil texture (see above).

4. The following is a table providing a tentative estimation of the relationship between soil depth, slopes and spacing apart soil bunds. However, there are other important considerations that should be well kept in mind:

Table 2 Distance Apart and Minimum Soil Depth Requirements for Bunds on Slopes of 5-35%

SLOPE (%)	DISTANCE APART OF SOIL BUNDS (METERS) — Minium Soil Depth Required								
	75 cm		50 cm				25 cm		
5	25	22,5	20	17,5	15	12,5	10	8	6
10	20	17,5	15	12,5	10	8	6	4	
15	15	12,5	10	8	6	4	2		
20	10	8	6	4	2				
25	8	6	4	2					
30	8	6	4	2					
35	8	6	4	2					
	100cm	75 cm	50cm	25 cm					

Terrace width below the -------- line is less than 5 m and not suitable for ploughing with oxen.

Farmers decisions often contrast with rigid technical specifications (see page 170). It is up to the field technician to negotiate a suitable or acceptable spacing. A larger spacing may be partially compensated by a larger and stronger structure but the benching effect is reduced or become very slow.

Only in exceptional circumstances, the vertical interval should be greater than 2 m and generally it should be restricted to 1.5 and preferably less, particularly in dry zones where peak runoff discharges are high.

The bunds must be adequately far apart to suit methods of cultivation (turning ploughs, etc.).

Dimensions: The dimensions of bunds should be such that they are sufficiently large and robust to withstand intense rainstorms and accommodate runoff or allow its partial evacuation safely (see provision of spillways, page 166). They should also tolerate a certain amount of trampling by livestock, which although highly undesirable is often inevitable. It is however recommended that animals should not trample over the structures at least up to the end of the first rainy season, when bunds naturally compact and are stabilized by natural vegetation.

The **height** would normally depend from the vertical interval. However, under the Dry Zone conditions, a minimum of 50-60 cm (1.5'-2') height after compaction is recommended.

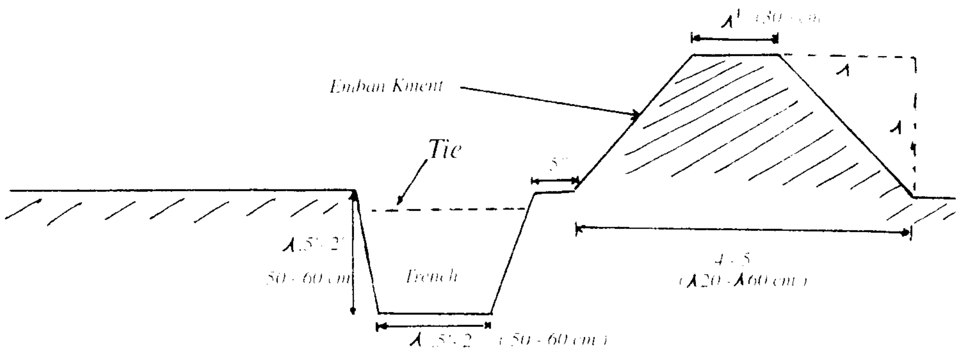
Top width of the bund is 1' (30 cm) but **base width** vary with the soil texture and hence its stability. For unstable soils (sandy loams) the width of the bund at the base should be 4-5' (embankment gradient 1:1) and for stable soils (clay loams, sandy clay loams) the width at the base should be 3' (embankment gradient 1 to 2 vert.).

The **collection ditch** should be 1.5' (50cm) deep x 1.5' (50 cm) wide or more based upon soil types. For unstable soils, 2' (60cm) x 2' (60 cm) is preferred. Narrow and deep collection ditches are preferred to large and shallow channels because the latter takes more space out of cultivation and more fertile top soil is used for the embankment. Ties should be placed at 10-20' (3-6 m) interval based upon distance apart and type of terrain, i.e. closer spacing if infiltration rates are slow in order to better control lateral movements of runoff. The height of ties are 5" lower than the total depth of the ditch to facilitate lateral movements of water within the collection ditch. In case of breakage due to layout or design errors, ties will hold most of the water and conserve soil in the remaining parts of the bunds left intact.

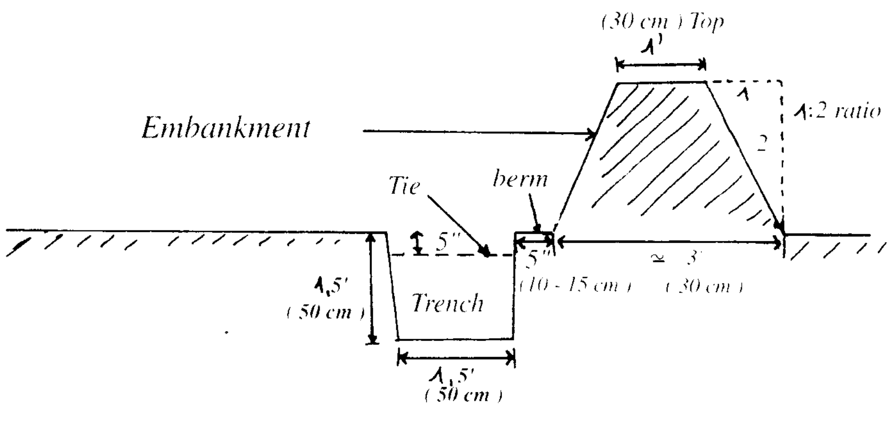
Length of bunds should not exceed 150'-250' to allow the passage of drought cattle from one plot to the next one. Length can be higher in case of gentle and uniform slopes and for bunds along farm boundaries.

Layout of bunds: the bunds are laid out along the contour using a line level fixed to a string attached to two poles or, in case of irregular slopes, using an A-frame (water level can be also used). The layout should take into account the technical requirements of spacing and dimensions of the structures, but also farmers suggestions and cultural practices (particularly ploughing). Layout in rough terrain should be carefully done, specially if the main slope bends also laterally in one or more directions. In this case contour lines change often direction and may not be accepted by farmers. A range of possible solutions to special cases is given in the following section.

Figure 5



i. Profile of bund and collection trench/ditch - unstable soil



ii. Profile of bund and collection trench/ditch - stable soil

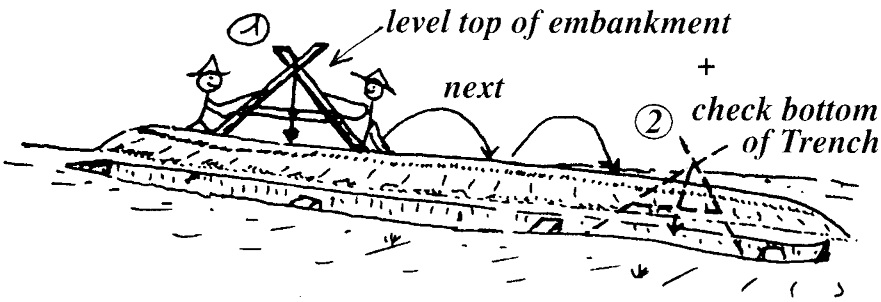
Layout of bunds using line level

Construction phases: After layout is completed with the approval of the farmers, construction should start at the top of the sub-catchment or field.

The collection trench or ditch is dug first. Excavated soil is piled downwards, 5 inches from the border of the ditch (berm). Layers of soil should be regularly and properly compacted until reaching the desired height.

Ties are left at regular intervals within the trench and the compacted embankment is shaped properly based upon the stability of the soil as mentioned above.

The **last most important operation is to check that the bottom of the trench within ties and the top of the embankment through its entire length are perfectly level.** Normally, an A-frame is suitable for this task (see figure below).



The formation of bench terraces occurs normally after 2-7 years based upon slope, spacing, type of soils and farmers willingness to speed up the process.

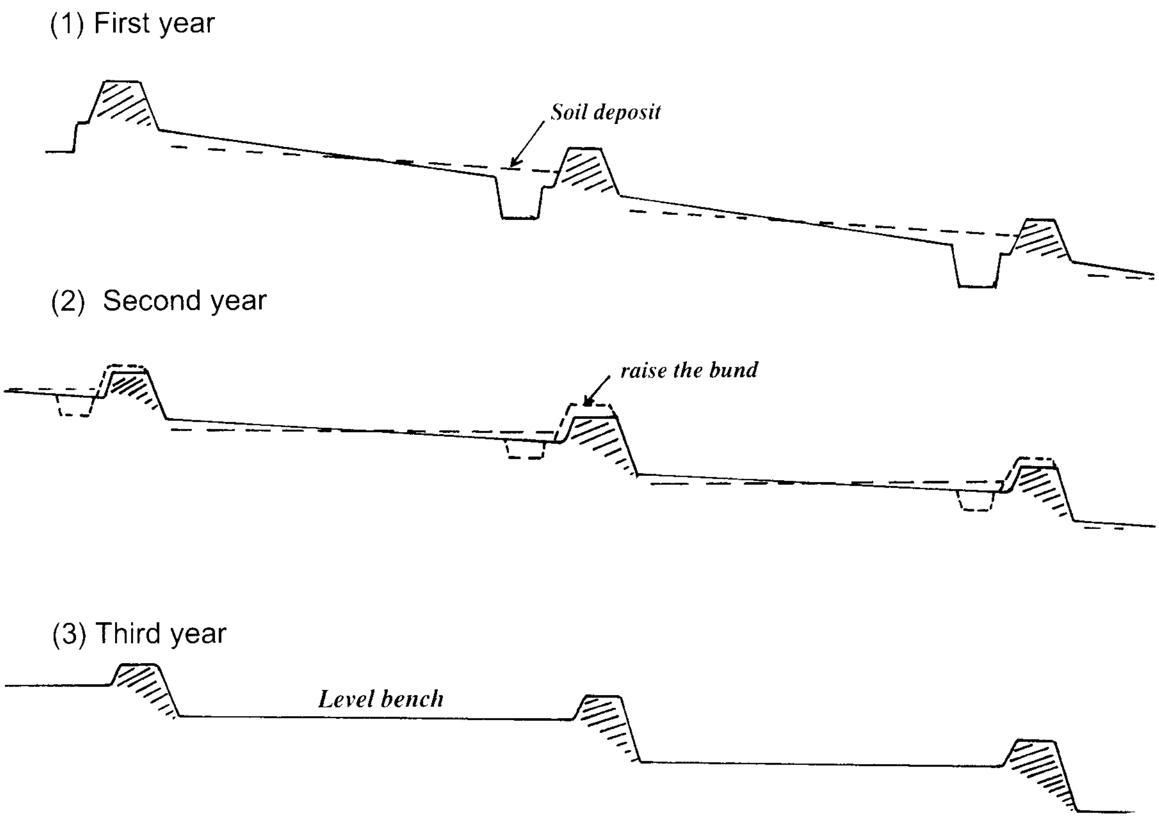


Figure 6   Formation of a bench terrace

Bund under construction and compaction (Chaung-Ma-Kyaukpadaung)

Checking the level of the top of the bund

Provision of spillways or excess water disposal devices: They are necessary when:

- the spacing between bunds is too large,
- where soils are heavy and slopes are gentle (<5%) and waterlogging problems may occur,
- on slopes between 10-30% where excess runoff may overtop the structure and create breakage and where soils have poor infiltration.

Spillways can be constructed in several ways:

(a) At the tip or end of the bund (lateral stone spillway) discharging water safely into natural hard pan & rock outcrop waterway running adjacently to the fields or into an artificial waterway/checked gully.

(b) Spillways can be constructed as stone checkdams on one side of the bund. They are generally constructed staggered from one bund to another; they should be provided with a large apron at their end/outlet, able to sufficiently disperse the water flow energy and not to create rills but slowly inundate the next plot until it spills through the next spillway.

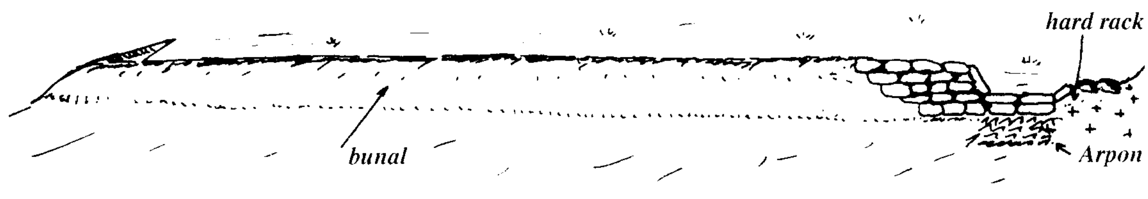
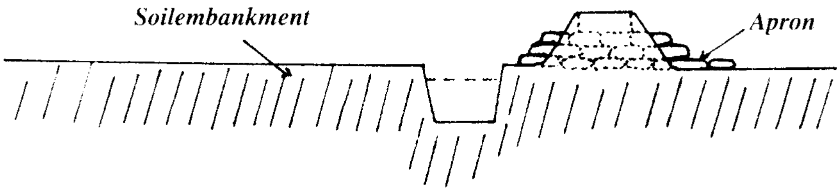


Figure 7 Spillway placed at the end of the bund (lateral)

Lateral spillway (Kuley-Kyaukpadaung)

Front view

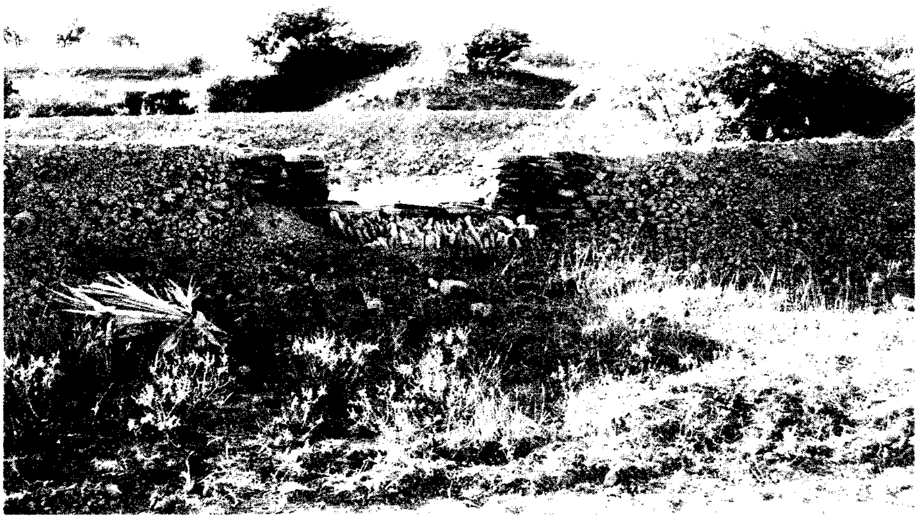


Cross section

Figure 8 Checkdam spillways on one side of the bunds

(c) Traditional spillways are also interesting such as the gated spillways used in Kembarte village - Kyaukpadaung, where excess runoff is allowed through a slot that can be sealed or opened at will.

(d) Spillways or stone reinforced outlets on bunds winging up laterally. The lateral bunds progressively decrease their height towards their tip or end which is reinforced with stones to allow the safely discharge of excess runoff laterally into the next field. In this case bunds should be constructed in a staggered position. Exception to this rule is when the wings can evacuate excess runoff laterally into a hard pan & rock outcrop or into a waterway running adjacently to the fields.



Spillway checkdam at the side of bund (Kyaukpadaung - Thee Kone)

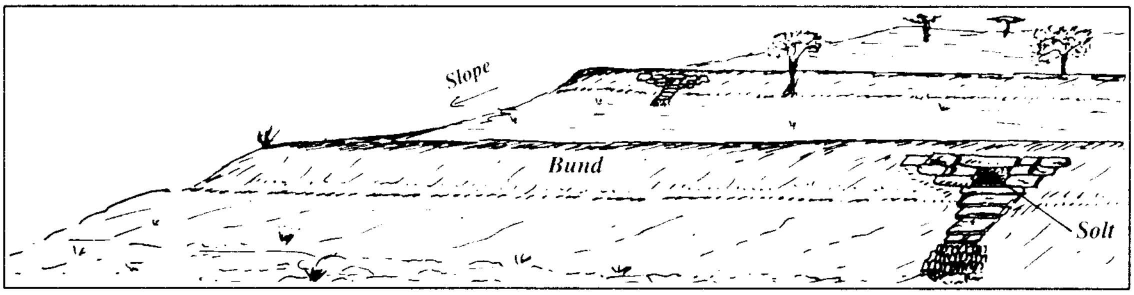
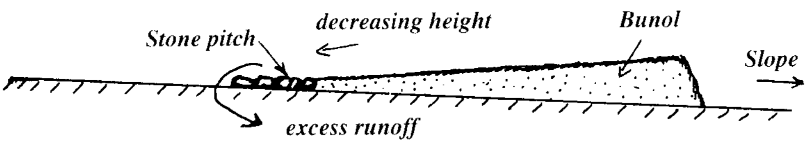
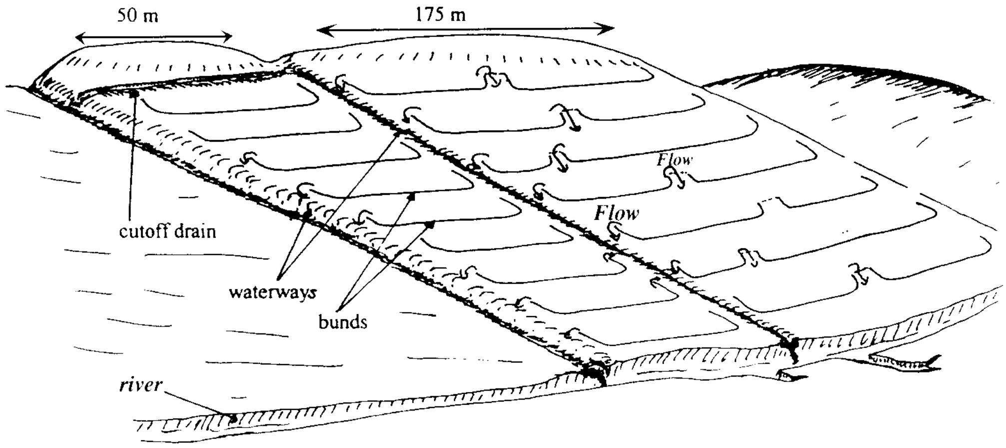


Figure 9 Soil Bunds + "gated" spillways

Traditional spillway with apron (drop structure) in Kenbarte - Kyaukpadaung



(1) Cross section



(2) Configuration of bunds which allow evacuation of excess runoff through lateral wings (staggered position or lateral)

Figure 10

(e) If stones are not available make wider spillways at the end of bunds. Stabilize the bottom of the spillway at 1' intervals with rows of scour checks made out of dry hard straws or grass. At the end of the rainy season they will stabilize with natural grasses. This option is only possible for slopes < 8%. In this case soil texture should be medium to heavy (not sandy & coarse). However, in case of sandy soils increase the number of scour checks (every 0.5').

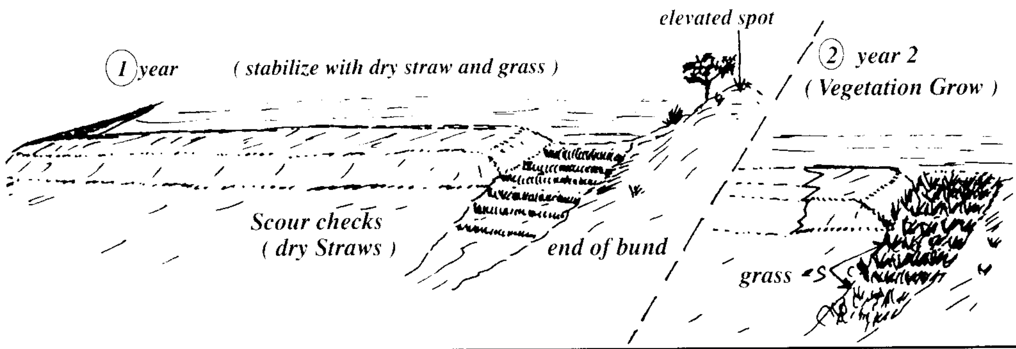


Figure 11 Spillway in areas without stones

Work norm: The work norm is estimated to be 1 person per day per 30-35' of bund length, depending on the type of soils. Though lighter soils are easier to work, the dimension of the bunds often exceeds the recommended standards in order to accommodate the appropriate leveling requirements and stability.

The work norm increases if spillways are inserted or reinforcements to the embankment are made. Generally, apply same work norm as for checkdams for the stone spillways. For stone reinforcement apply the general rule of 50 cubic feet of stone work per person per day (including transport and foundation).

Integration requirements: the following are but a few activities that should supplement and integrate soil bunds.

Bund stabilization: various crops, forage species of grasses and legumes, shrubs and trees can be used for bund stabilization (see section on stabilization of physical structures-Biological measures, page 271).

Agronomic practices: mulching of crop residues, tie-ridging, compost application, contour ploughing and planting, ripping hard pans and sub-soil, intercropping, etc., are some of the most important biological measures that should be integrated with bunding (see biological measures).

Control grazing: the areas treated with bunds should be protected from cattle trampling up to the end of the first rainy season and possibly longer.

Cutoff drain construction above bunded fields: wherever unprotected and untreated hillsides are located above cultivated areas with bunds, excess runoff from these hillsides should be intercepted and diverted into a natural or artificial waterway. This is possible by constructing a cutoff drain above the bunded area (see cutoff drain construction, page 224).

Bunds can be constructed in combination with grass strips or alley cropping (1:1 ratio) in gentle slopes and fertile soils (see page 267). However, the free grazing practice makes this option an unlikely possibility.

Inputs requirements: incentives (cash, others) may be required in situations of chronic poverty and the need to assist deprived households. In addition to the line level, poles, string, a meter tape, an A-frame and a simple clinometer are needed. Materials such as digging tools (shovels, hoes and crow bars) are also required. Other inputs may include planting material (seeds, cuttings, seedlings, etc.) for stabilization, for instance for those species not available locally or not known by farmers which may be suitable for the area and need to be grown in nurseries.

Management and Maintenance: this include the upgrading of the bund every year until bench terrace is developed, the repair of breakage after intensive storms, the proper maintenance of vegetation on the bund, control grazing and repair/consolidation of spillways if any.

Training requirements: training of farmers in layout and construction of soil bunds. This may include training in upgrading, revegetation and management of bunded areas. Training may also emphasize on group formation.

Limitations refer to labour availability for construction and maintenance of bunds, tenure issues, spacing taken out of production by the bunds if too narrow spaced (2-10% depending on slope and intervals), lack of skills, etc.

Variations to the Original Design

COMMON CASES WHERE FARMERS DO NOT AGREE WITH THE STANDARD TECHNICAL RECOMMENDATIONS: ADAPTATION OF INDIGENOUS AND NEW TECHNOLOGY

During layout and design of bunds field technicians should be paying attention to the following common situations:

(i) Farmers are reluctant to follow exactly contour lines and want to cross slight depressions straight.

- In this case, suggest for an increasing of the size of the bunds in coincidence with the depression points. Although contour lines are not exactly correct, they are compensated by stronger embankments at depression points. However, the top of the entire length of the bund should be leveled.
- Since water pressure would be higher at depression points, bunds should be constructed on top of a stone key (depth 1' and width 1,5') that is about 2' high, covered with soil and well compacted until it reaches the same level of the top of the two joining embankment sides.
- The depression area should be further strengthened with a stone wall on one or both sides of the embankment.
- In absence of stones, a brushwood check should be placed in the downstream side of the bund to act as a stone riser. Eventually, a spillway should be constructed opposite to the depression to allow overflow and decrease water pressure. For the same reason, this type of bunds should also wing up laterally and be reinforced with stones.

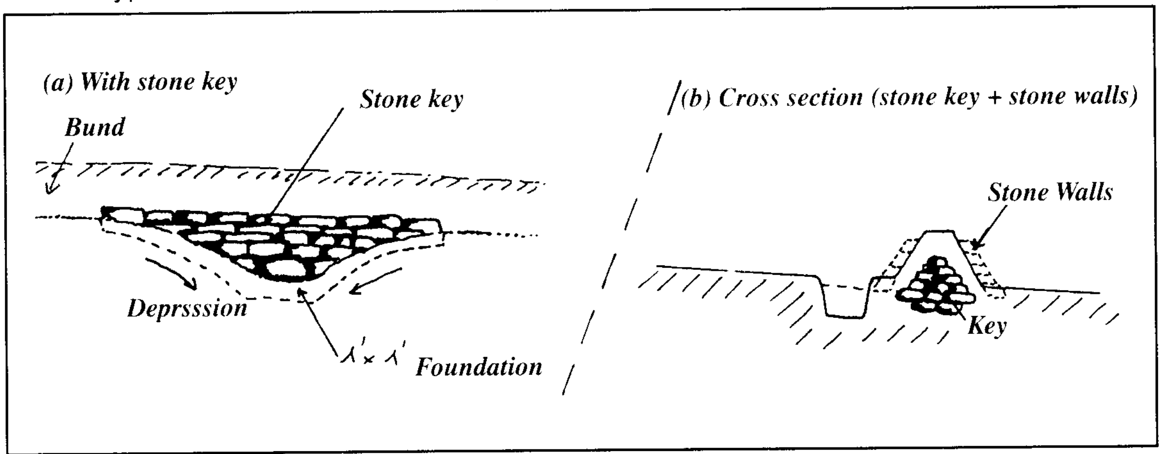


Figure 12 Reinforcement of bunds in slight depression points

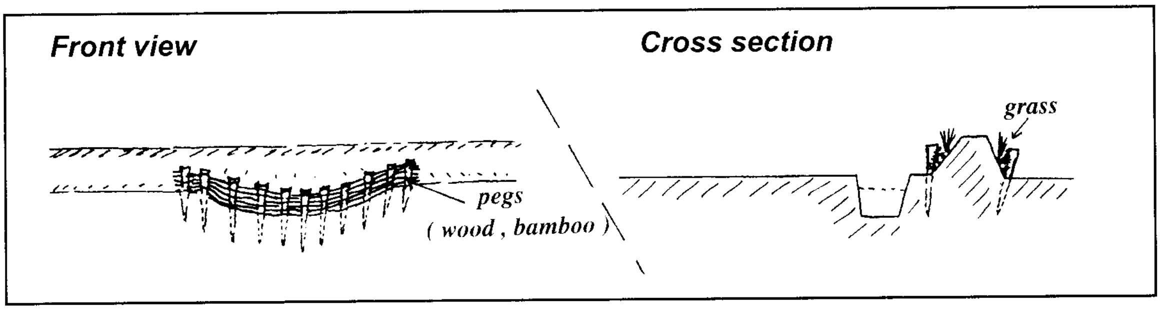


Figure 13 Reinforcement of bunds in slight depression points using brushwood checks

(ii) Farmers insist to have boundary bunds only and refuse to break long slopes with additional bunds.

- Bunds along boundaries have the great advantage not to interfere with crops and farming operations. In several parts of the Dry Zone farm boundaries seem to follow an approximate contour.

- In case of wide open fields, the technician should negotiate additional bunds or, if this is not possible, a stronger design for the bunds that are already agreed. For this purpose, spillway devices are recommended. **Corners should be strengthened with stone walls (figure 14). The top of bund must remain level.** Boundary bunds may wing up laterally.

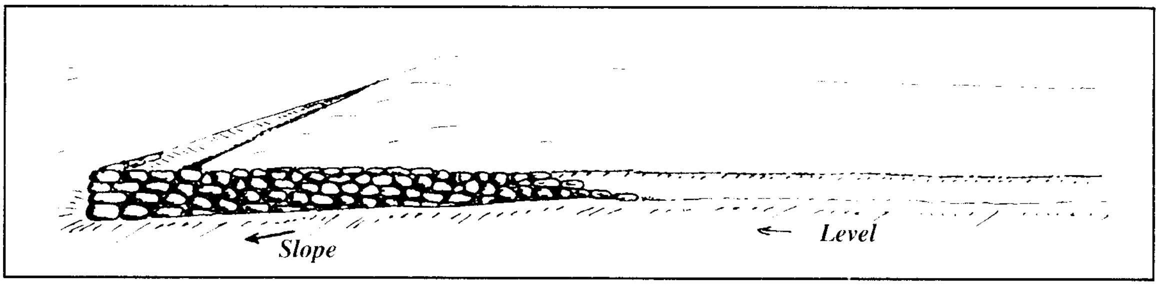


Figure 14 "Corner" or lateral stone reinforced soil bund

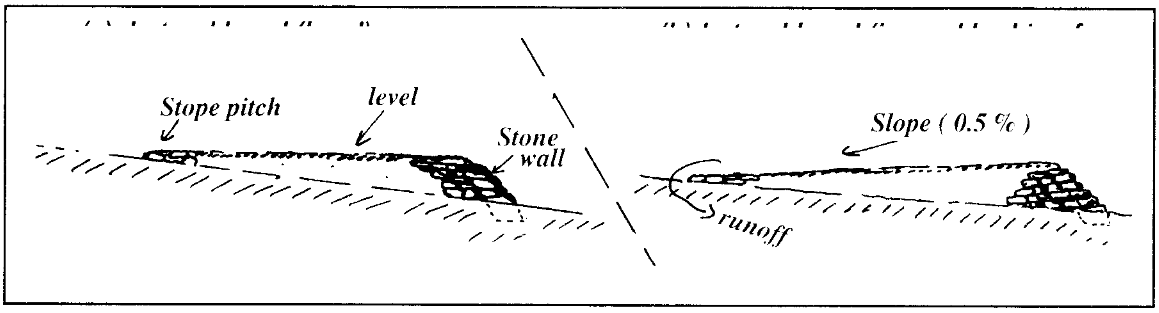


Figure 15

(iii) Combination of i) and ii) situation

Apply a combination of both recommendations.

It is also suggested to provide these bunds with lateral or side checkdam spillways as an additional precaution.

(iv) Soil bunds in shallow soils and soils prone to piping problems

The following design is applicable under two main conditions:

-> Shallow soils with slopes < 10%.

-> Sodic soils, soils with heavy clays mixed with heterogeneous materials.

A strong boundary bund constructed in (Thee Kone - Kyaukpadaung)

On shallow soils, bunds can be constructed to slow-down runoff and retain moisture. They would unlikely bench throughout their entire width unless on gentle slopes (< 5%). Because of such depth limitations it is recommended to construct **soil bunds provided with shallower and wider collection ditches.** The embankment has the same dimensions as above and the only difference is on the water collection ditch which has generally a width of 4-5' and a depth of 5". The bund embankment is constructed by scratching the soil from such a wider area. In view of the limited infiltration expected from such type of soils, it is recommended to provide bunds with a spillway. A disadvantage of this type of design is that a wide portion of fertile top soil is used to construct the bund and the fact that a wide portion of land is likely to remain out of production the first year. However, in case of soils not too shallow, cultivation of crops can be extended up to the embankment although only with waterlogging resistant species.

On sodic soils or soils with clays mixed with heterogeneous materials, the vertical pressure of the depth of water in normal bunds (narrow and deep collection trench) may encourage piping and tunnelling starting from the bottom of the trench and proceeding downwards under the bund until exiting in the field located below. Therefore, to decrease such pressure the same design for bunds as indicated above for shallow soils is recommended. To further decrease the risks of piping, the bunds should be stone faced on both sides and provided with a spillway.

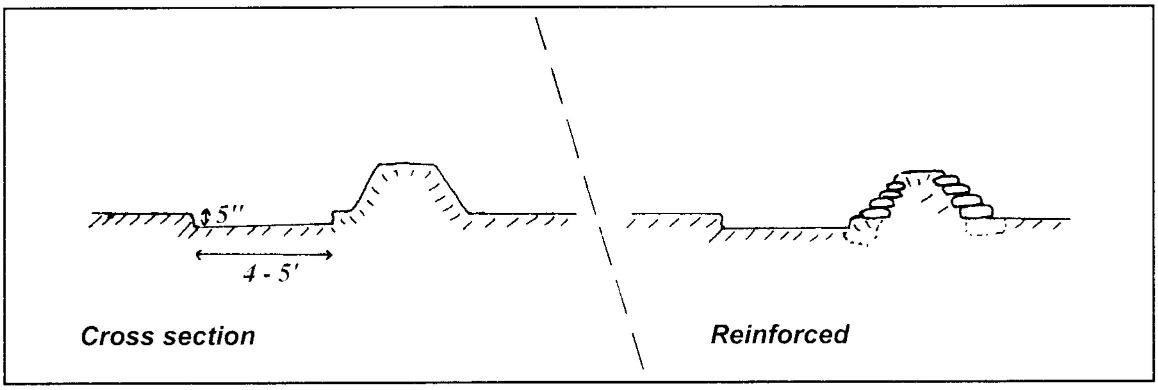


Figure 16 Soil bunds in shallow soils or soils prone to piping

(v) Farmers *do not agree* with the recommended dimensions of the structures.

Discussions to overcome their reluctance to follow the required standards is necessary. However, if the farmers are rigid beyond acceptable terms of compromise, do not insist for implementing bunds or whatever measure since failure is likely to occur. In this case, technical and financial/material support should also be avoided.

Concluding, under Myammar conditions, additional testing is required before working out precise recommendations on spacing and dimensions because soils and rainfall intensities vary widely.

The current strategy is to remain safely within correct ranges of technical specifications, particularly when soils have surface crusts (common situation) which decrease infiltration rates and yield high runoff during intensive showers. **Therefore, construction standards should be kept high.**

Example of well laid out and constructed soil bunds (Chaung-Ma, Kyaukpadaung)

Silt deposit along collection ditch after a rainstorm (Kenbarte - Kyaukpadaung)

Cropped fields with soil bunds after first rains (Kuley - Kyaukpadaung)

Water harvesting & retention effect of soil bunds in the Dry Zone: Note the difference in crop performance between treated fields with soil bunds (lower part) and untreated (upper part) areas in Indaing Gyi - Magway Township.

STONE FACED AND REINFORCED SOIL BUNDS

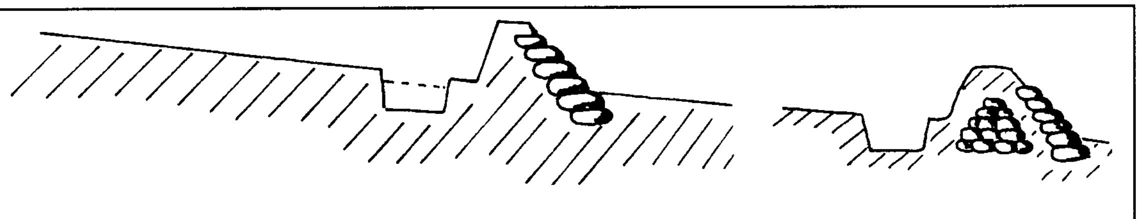
Definition and scope

Stone faced **soil bunds are soil bunds further strengthened on one or both sides of their embankment with a stone wall or riser.** In some instances, the reinforcement may take place only along the depression points mentioned above to compensate for layout problems (see soil bunds) or, as emphasized here, **to protect the entire length of the bund.** The strengthening of soil bunds with stones throughout their entire length is recommended wherever farmers tend to increase the spacing between structures and stones are available.

Technical specifications

- ***Slope range:*** the slope range may increase up to 50% slope compared to soil bunds alone. However, on such extreme slope range, the spacing apart bunds should be guided by standard technical recommendations (relationship between slope, vertical interval and soil depth). Besides, above 30% slope the stone riser of the downstream embankment should have a deep foundation (1'). Generally, spillways are required above 10-15% slope or even less if waterlogging problems are likely to occur.
- ***Type of soils:*** in all type of soils, excluding sandy soils. For ***soil depth*** and ***texture*** same as for soil bunds. Stones should be available from the field itself or from adjacent areas.
- ***Spacing apart soil bunds:*** the spacing may be slightly wider than for soil bunds, particularly up to 15% slope (add 10% to the table).
- ***Dimensions:*** the dimension of the bunds are identical to the ones already explained. The difference is on the stone walls placed on one or both sides of the soil bund. Therefore the bund is larger and stronger.
- ***Layout of bunds:*** bunds should be level and wing up laterally in order to evacuate excess water. As mentioned for the layout of soil bunds, farmers may want to cross small depression points straight instead of curving up and down hill continuously. In this case the entire bund should be reinforced on both sides, including a stone key.
- ***Type of stone reinforced soil bunds***

  Single faced stone protection wall + collection trench: stones are placed on the downstream side, well inclined to offer maximum resistance (1:1 - 1:2 vert.). A collection trench is dug on the upstream side of the bund (Fig.17). They are provided with spillways above 10% slope or less if necessary (spacing, type of soils and type of crops). Stone keys are also applied in depression points if any.

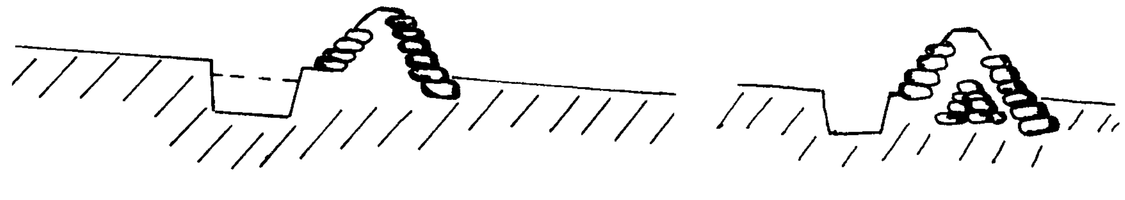


Cross section of single faced reinforced bunds(entire length) *With stone key*

Figure 17

F-2

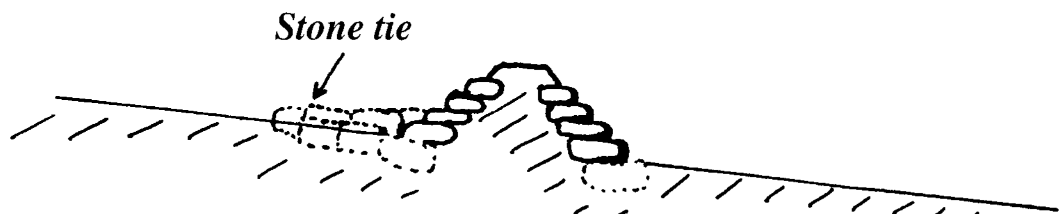
Double faced stone/soil bunds + collection trench: both sides are reinforced with stones. This type of bund is rather resistant against excess runoff (Fig 17). Stone keys along depression points within the earthen part of bund should also be applied as required.



Cross section of double stone reinforced bunds ***With stone key***

Figure 18

Double stone faced soil bunds with spillway under construction (Li Pin - Kyaukpadaundg)



Cross section

Figure 19

Double faced stone/soil bunds without collection trench: they are suitable for gentle and uniform slopes (<10%). The soil embankment is obtained by scratching a wider and shallow layer of topsoil. Small ties can be placed at regular intervals along the upper side of the bund (Fig.19).

"Corner" or lateral stone/soil bunds: This type of corner or lateral bunds differs from those explained for soil bunds because they are stone faced on both sides and through their entire length (Fig.20). They are suitable for lateral field boundaries with gentle slopes (<5%) where farmers want to extend their bunds without following a precise contour line. The bunds should then be raised at those corners and strongly reinforced on both sides with stones. The tip of the bunds winging upwards, whilst remaining level, are of decreasing height towards the slope (Fig. 21-a). They may also evacuate excess water through their tips if their top level decreases inwards (Fig. 21-b). The bunds can also be provided with spillways.

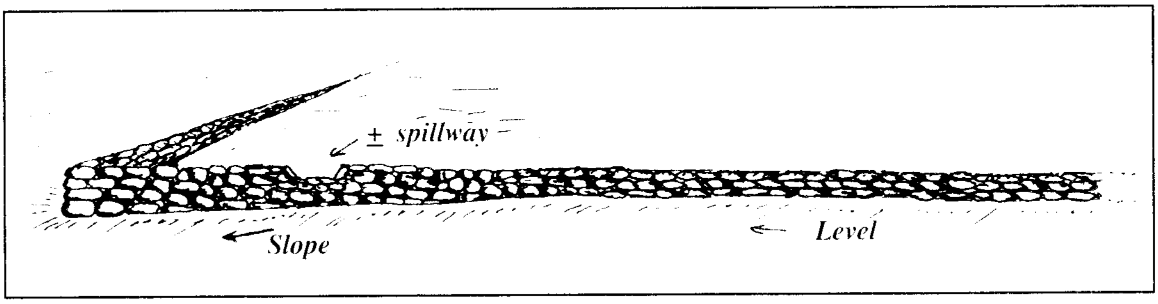


Figure 20 ***"Corner" or lateral stone faced bunds***

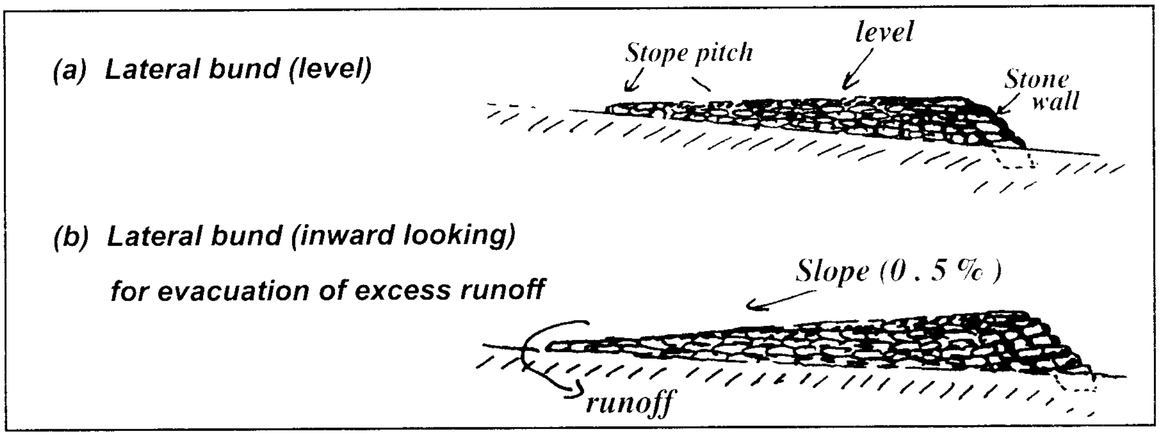


Figure 21

Example of "corner" or lateral bunds (Thee Kone - Kyaukpadaung)

Construction phases for all stone faced bunds: construction starts by digging a foundation 1' wide and 0.5'-1' deep. Large stones are then placed in the ditch with the right inclination. Soil is then dug from a trench on the upper side and, together with smaller stones, fill the empty spaces under and between the large stones. A ladder shaped positioning of the stones is recommended. The rest of technical specifications are identical to soil bunds.

Provision of spillways or excess water disposal devices: spillways can be placed at the end, in the middle or in whatever convenient (often staggered) position is considered adequate. An apron is also recommended at the spillway outlet.

Work norm: the work norm is approximately estimated to 1 person day for 15-25' of bunds depending on soils and availability of stones and shape of stones.

Integration requirements: same as for soil bunds.

Inputs requirements: same as for soil bunds, except for higher labor. Concerning materials, crow bars and sledge hammers are important to dig out and break stones.

Management and Maintenance: well constructed bunds would need little maintenance, except for the increasing of the bund height once the collection ditches are full of sediments. Then increase the height of the wall following the same procedures indicated above. Control grazing should be ensured for a full year until stabilization and settling of stones/soils is completed.

Training requirements: This type of structures need skilled labour in dry masonry works, i.e. shaping and positioning of stones. Farmers should be well trained and supervised regularly.

Limitations: same as for soil bunds (+ more labour).

LEVEL STONE BUNDS

Definition and scope

A level stone bund is an **embankment made of stones constructed along the contour (points of the same elevation) across sloping lands, without a collection channel or basin at its upper side.** Soil which is eroded between two bunds is deposited behind the lower bund. Stone bunds are either impermeable structures if their upstream side is sealed with soil or semi-permeable. However, the deposition of eroded soil along the bund will decrease its permeability after few rains. Whenever the bund has trapped enough sediments, the bund should be raised. In this way, a **bench terrace** will develop in the course of years (3-7 years based on slopes and type of soils).

The function of stone bunds are identical to soil bunds. They are preferred to soil bunds in areas having abundant stones and are recommended for slopes higher than 15-30% for their superior stability and resistance against runoff. In Kyaukpadaung, farmers practice traditional forms of stone bunds in several areas.

Technical specifications

Slope range: slopes range between 5% and 50%, following the relationship between vertical interval, bund height and slope % shown in the table below.

Type of soils: stone bunds will be constructed in areas with stoniness >15% and < 50% and with soil depth of at least 50-100 cm. For shallower soils, stone bunds can still be constructed but would not form a bench terrace. In this case they should be considered as semi-permeable structures, which reduce runoff velocity and erosion.

Spacing apart stone bunds: the following relationship is provided for stone bunds and should be considered only indicative

Ground slope %	Height of bund (m)	Vertical Interval (m)	Distance apart (m)
5	0.50	1.00	20
10	0.50	1.50	15
15	0.75	2.20	12
20	0.75	2.40	10
25	1.00	2.50	8
30	1.00	2.60	8
35	1.00	2.80	6
40	1.00	2.80	5
50	1.15	2.80	4

Table 3 Recommended height, Vertical interval, and Distance apart for stone bunds

Dimensions: the height is given in the table above. The top width of the bund should, for all heights, should not be less than 1' (30 cm). To counter the pressure from the soil which will accumulate in due course on the upper side, the lower face should slope at a grade of 1 (horizontal) to 3 (vertical), while the upper face, should not be steeper than 1 to 4. This grade may be used where large flat stones are available for construction. Smaller or slightly rounded stones will necessitate for the construction of the face at a more gentle grade, 1:2 and 1:3 respectively. The foundation, placed at the lower side, has a width and a depth of 1'.

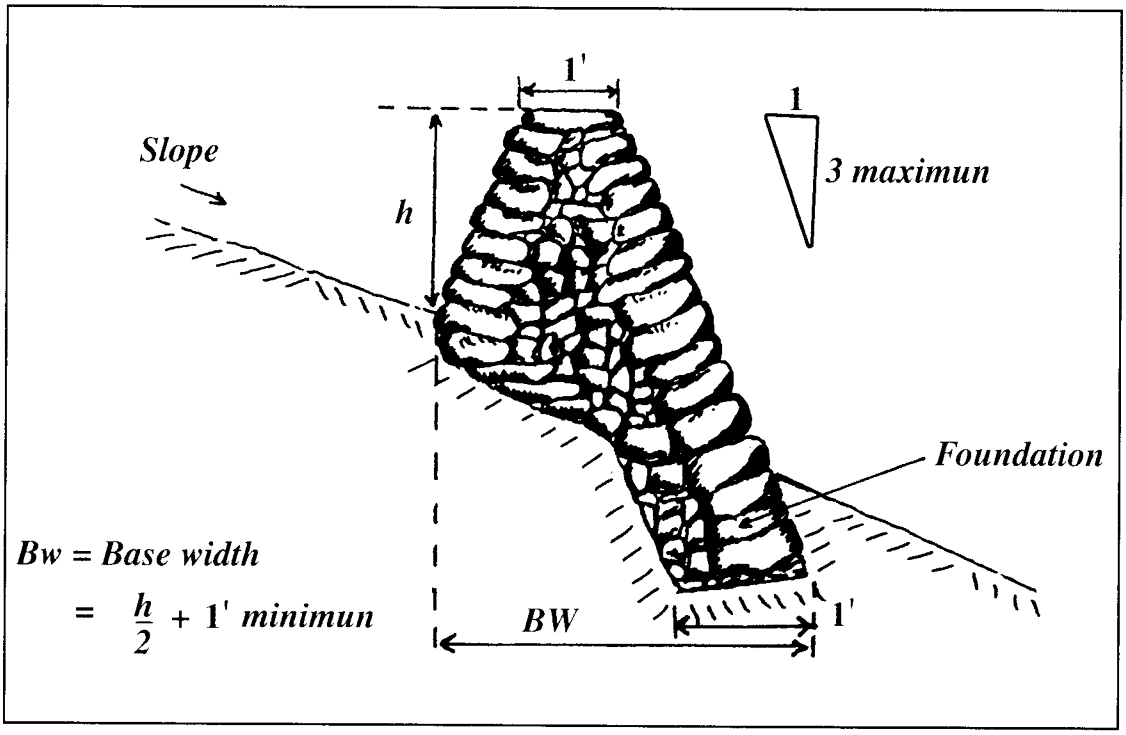


Figure 22 Grade of face and top width of stone bunds

Layout of bunds: same as for soil level bunds

Construction phases: The construction of stone bunds, that may last for many years and may be heightened from time to time as the need arises, require some care in the selection of stones, their placing and the provision of **a stable foundation**. The bottom of the foundation should slope slightly so that the flat stones when built up will be inclined backwards. Then proceed placing the stones one on top of the other on both lower and upper side and **seal up gaps** between the large stones with small and more rounded stones. On completion of the stone work a **layer of soil** should be placed on the top and upper side of the bund. It will reduce the flow of runoff through the bund and encourage the growth of grass. Low stone ties can be placed every 10' along the contour to decrease possible lateral movements of water. Bunds should **wing uphill**, progressively decreasing their height towards the slope. Every year, observe sediment deposition and **raise the height** of bunds (Fig. 23).

Provision of spillways or excess water disposal devices: they are normally not necessary unless for heavy soils and large spacing between bunds.

Work norm: The norm is approximately fixed to 1 person per day per 25' of stone bund construction, including the transport of stones. If stones are not available locally (in situ) but can be brought from the vicinity, the norm may change up to 20' per person per day.

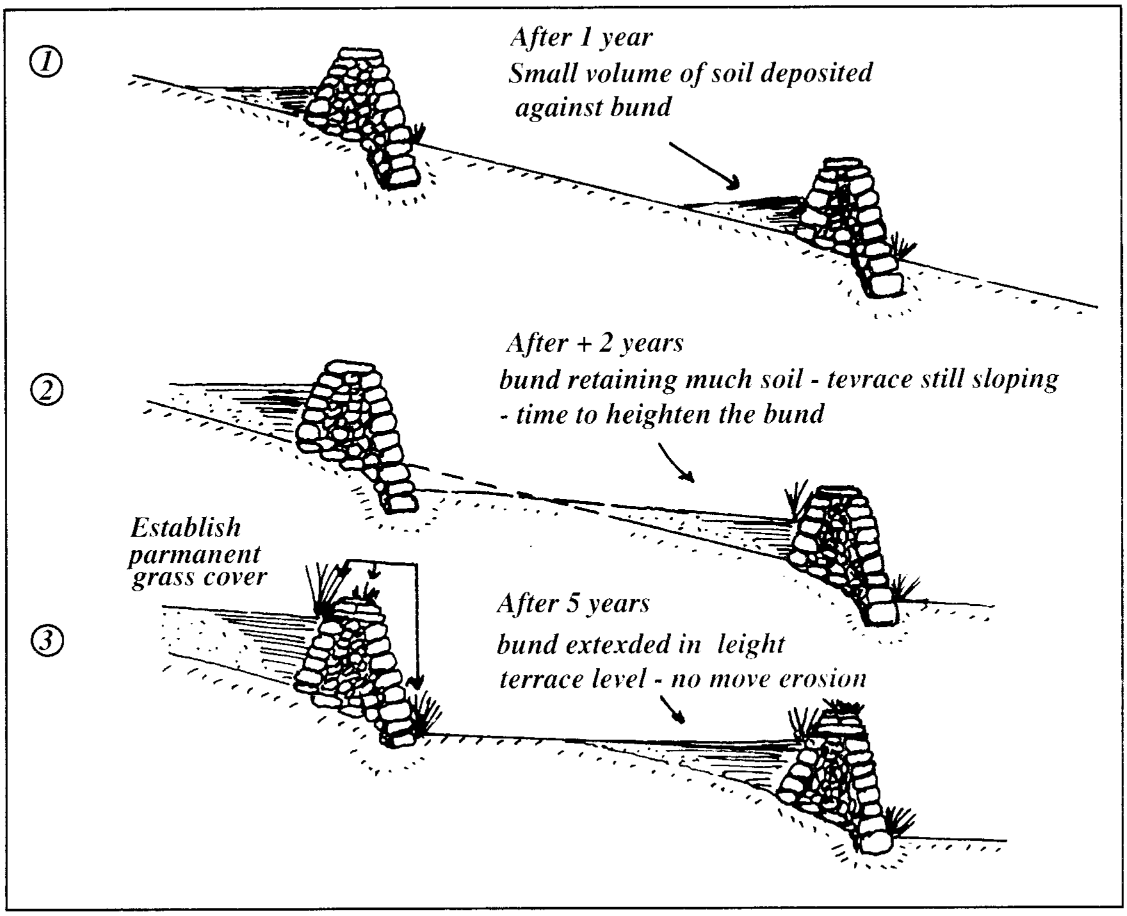


Figure 23 The formation of Stone Walled Terraces

Integration requirements: same as for soil bunds.

Inputs requirements: same as for stone faced bunds. However, for the transport of stones may be facilitated by the use of bullock carts. Tools such as crow bars and sledge hammers (to shape the stones) are necessary.

Management and Maintenance: when well constructed little maintenance is required except for heightening the bund. Cattle trampling is to be avoided for one year.

Training requirements and limitations: same as for stone faced soil bunds.

Variation to the Original Design

COMMON CASES WHERE FARMERS DO NOT AGREE WITH THE STANDARD TECHNICAL RECOMMENDATIONS: ADAPTATION OF INDIGENOUS AND NEW TECHNOLOGY

1. **Farmers do not agree on the distance between bunds and want wider spacing (for example only boundary bunds or large spaced bunds).**

Bunds will not accommodate the whole runoff and are likely to be over topped and damaged (stones dislodged, collapse of walls, etc.).

Solution (a) ⇨ *Provide stone bunds with spillways.*

Similarly to soil bunds, make one portion of the stone bunds like a spillway and check dam (Figure 24). The spillway should be placed towards the end of the bund side. If spillways discharge their excess runoff into the next field they should be placed staggered one from another. Exception to this rule is when bunds can evacuate excess runoff laterally into a hard pan and rock outcrop or into a waterway running adjacently to the fields. Spillways can be closed or opened at different heights based upon how much and for how long farmers want to retain water within their fields.

However, in this situation it is very unlikely that the areas delimited by stone bunds will be converted into benches (except if soil is deep). Nevertheless, some moisture will be trapped and runoff slowed down whilst some soil will accumulate in the lower portion of the fields.

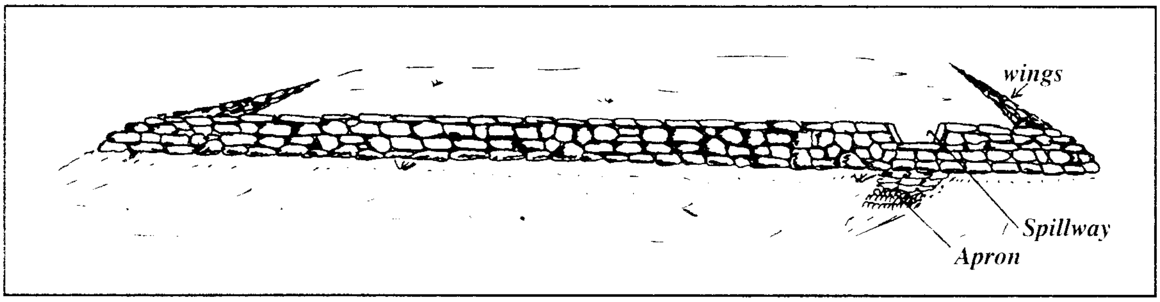


Figure 24 Stone bunds + spillway at the end of bund

Solution (b) ⇨ *Provide stone bunds with a water collection ditch placed in the upper side and increase the size of the stone bund (Figure 23-a).*

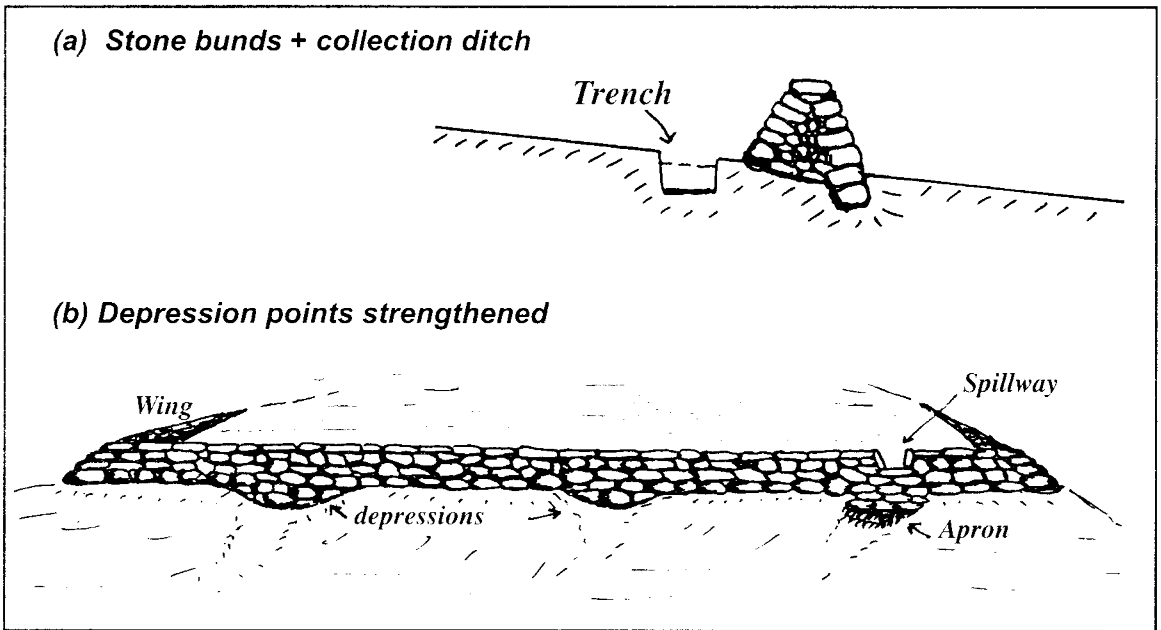


Figure 25

Solution c) ⇨ *Combine a) and b). This option should always be considered when slopes are 15-50%. Remember that stone walls should be provided with a solid foundation and stone work should be ladder shaped.*

2. **Farmers are reluctant to follow exactly contour lines and want to cross slight depressions straight (to facilitate their farming operations).**

Solution d) ⇨ *In this case increase the size of the bunds in coincidence with the depression points (stronger stone wall and foundation). The top of the entire length of the bund should be leveled. Fill any depression area* *behind the wall with good soil. Normally, lateral spillways are also required to allow overflow and decrease water pressure (see Figure25-b). This type of bunds should also wing up laterally.*

Most of the situations presented above can occur in different combinations and patterns based upon the field conditions (slope, type of soils, presence of stones, etc.) and farmers' desire. Hence, the different solutions presented above can be combined in various ways to accommodate the different possibilities.

Stone bunds on steep slopes in Kenbarte-Kyaukpadaung

BENCH TERRACES

Definition and scope

Bench terraces are conservation structures, usually along the contours, where a slope is converted into a series of level or nearly level steps or benches. Since they require a considerable amount of labour they are generally used on steep slopes (>20%). Maximum control of runoff and erosion is achieved when an entire hillslope is terraced and cropped. They are used mainly to support the growth of perennial crops or highly valued crops. In the Dry Zone, bench terraces evolving from traditional bunds are observed in numerous locations.

Technical specifications

Slope range: they are suitable in any kind of slopes but recommended above 20% slope because of the labour requirements.

Type of soils and spacing apart bench terraces: As a guide, terraces should be spaced with a vertical interval which is two and an half times the usable soil depth. If the soil is one meter deep, the vertical interval is 2.5 meters.

Dimensions: The width of the cultivated area is determined by the slope gradient and the soil depth as shown in the table below.

Slope	Soil depth (cm)					
gradient	25	50	75	100	125	150
20%	2.81m	5.63m	8.44m	11.25m	14.06m	16.88m
30%	1.77m	3.54m	5.31m	7.07m	8.85m	10.63m
40%	1.25m	2.50m	3.25m	5.00m	6.25m	7.50m
50%	0.94m	1.88m	2.81m	3.75m	4.69m	6.63m

Table 4 Width of cultivated land on bench terraces in meters for variable slopes and soil depths

Layout of bench terraces: bench terraces are level along the contours in dry zones. However, different shapes and leveling is possible based on soil types, crop water requirements and rainfall intensity. For instance outward-sloping terraces may evacuate excess runoff (heavy soils), reverse or inward-sloping would keep water longer and concentrate moisture on its lower point (soils with good infiltration, highly valued crops, etc.). Level terraces have a small embankment at their edge.

Construction phases: bench terraces are constructed by cutting and filling. First the top soil is removed and kept aside. Then the cutting and filling continues until the bench is formed. Finally, the top soil is replaced on top of the field. The riser can be reinforced with a stone wall (see stone bunds) or revegetated promptly with grass and legumes.

Provision of spillways or excess water disposal devices: they are not required but on heavy soils, terraces may be constructed with a slight gradient along their length so that runoff flows to a discharge point (natural or artificial waterway).

Work norm: Normally, an estimated 180 person days are required per acre of bench terrace formation.

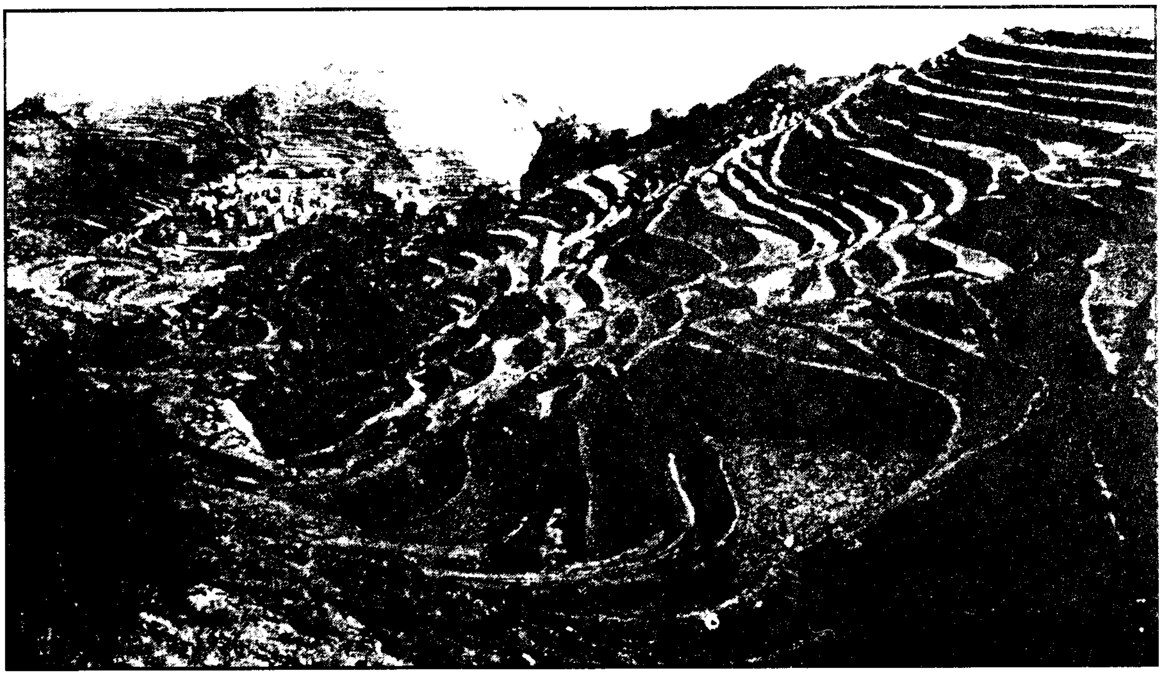
Integration requirements: same as for bunds. Bench terraces for food crops can alternate with terraces for tree or forage crops. In some cases trees, forage species and food crops are intercropped within the same step or bench.

Inputs requirements: labour is the main requirement. It is preferable to obtain bench terraces gradually, for instance through soil or stone bunds.

Management and Maintenance: they require control control grazing, specially on steep slopes and regular maintenance of the stone or vegetated riser until the terrace stabilizes.

Training requirements: same as for bunds + very accurate layout.

Limitations: mainly labour, the measure may be suitable only for highly valued crops.



Bench terraces in Yemen (H. Vogel)

F-

RENOVATION OF TRADITIONAL BENCH TERRACES

Definition and scope

Traditional bench terraces are observed in numerous locations of the Dry Zone. They are formed either in one go, **by leveling the land with traditional bullock-drawn plough and scraper-levelers, or by the gradual raising of traditional bunds over several years.** In most fields the embankment is provided with a rudimentary spillway able to evacuate excess runoff. It may be difficult to differentiate bench terraces from SS dams because the latter do also form bench fields after one or more rainy seasons. However, in the Dry Zone bench terraced fields are those fields located along wide but not deep drainage lines and along side slopes of upland areas. They are also built in series but, compared to SS dams, they are not served by wide catchment areas.

The main objective of renovating traditional bench terraces is **to improve valuable land assets which are either damaged or likely to be damaged in the future. The intention is to rehabilitate, renovate or improve bench fields which are potential areas for introducing better cropping patterns and high yielding varieties.** Other advantages are similar to the ones described for soil bunds.

Why damage and destruction of valuable traditional Bench Terraces occurs?
In several locations, traditional bench terraces are damaged by excess runoff and related piping or over-topping problems. This happens because:

- ***The benched fields do not have well designed spillways*** able to evacuate excess runoff coming from the upper reaches of a catchment area. Then breakage occur in one or more points along the terrace embankment, creating a chain effect of damages to the structures located downslope.
- ***The type of soil is prone to piping*** (mix of heterogeneous materials, e.g. swelling clays mixed with soluble materials and sands). During the dry season these soils present wide cracks where water from heavy showers infiltrate rapidly and reach the impervious plough pan layer. Then water moves through the cracks horizontally, melting and pressing the materials until reaching the end of the bench embankment. A pipe or a small tunnel is then rapidly enlarged by the flowing water until the whole structure eventually collapses.
- ***In most cases, these two factors are jointly responsible for the breakage of the terrace.*** Too much water held by the bench terrace increase the hydraulic pressure over the soil, making it easier to pipe. However, damages can also occur only by violent over-topping and erosion of the spillway or both.

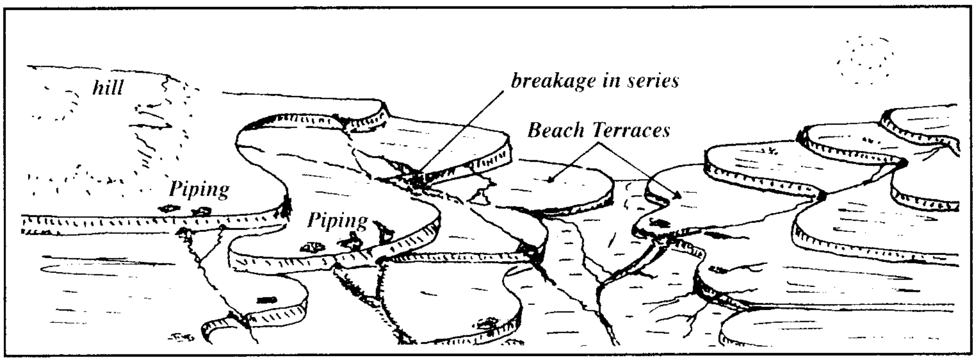


Figure 26 Damages to bench terraces

Technical specifications

Slope Range and type of soils: The slope should be level or not exceed 3%. Soils are normally deep but impervious plough pans are common, which reduce infiltration and makes the soil sensitive to piping.

Treatment sequence: Bench terraces can not be treated in isolation but in series within a sub-catchment. Therefore a concerted approach involving all farmers within one sub-catchment is required. Every farmer should agree about the measure.

Construction phases and dimensions: The following steps are recommended.

- **Reshape the piped and broken areas** and fill them with good soil. Make use of bullocks and traditional levelers & scrapers to fill and level the area.
- **Build a strong soil embankment and reinforce the formerly piped or broken sections with a stone wall** (see Figure 27).
- Fill the rills or portions of the field which have been dissected or gullied by scraping and leveling the soil within the plot. Because the slope is gentle, the leveling and filling of depressions is normally not required over the entire area of the plot.
- The embankment is made out of the soil scraped along the edge of the terrace. The bullock drawn leveler pushes the soil towards the edge of the terrace and laborers pile and shape it in order to form a stable embankment. The embankment should be perfectly level.
- The base width of the embankment range from 4 to 6' and top width 1.5-2.5'. The bund height range from to 2 to 3'. No collection trench is required.
- A checkdam is constructed and inserted at one side of each bench terrace embankment. The size of the checkdam spillway vary according to the catchment area. For catchment areas > 2 acres refer to the spillway design indicated for SS bunds. Otherwise follow checkdam spillway design. Most important is that the level of the spillway must not be higher than 4" from the ground level (depth of flow 4") to avoid piping problems. The checkdam must be provided with a wide apron. If bench terrace length is over 200' provide two spillways on both sides.

Input requirements and work norm:

Leveling: 1 pair of bullocks for 2 days/acre of land approximately (wide variations may occur based upon the amount of soil needed for leveling and filling).

Terrace embankment: 1 person per day/30' of embankment.

Checkdam: 1 person per day per 3' of linear checkdam work.

Stone walls reinforcements: 1 person/day/ 35' cubic feet.

Tools such as spades, pick axes, A-frame, plough, leveler, etc.

The above requirements may change based upon soil type and availability of stones.

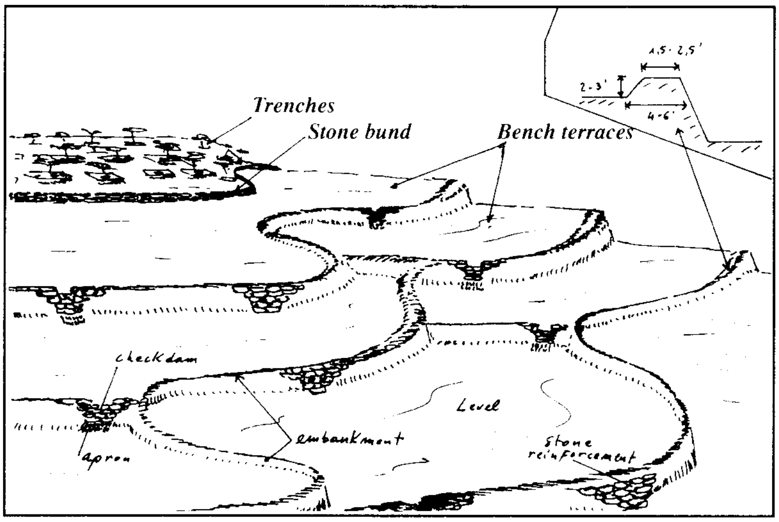


Figure 27 Renovation of bench terraces

Traditional bench terrace renovation in Thee Kone - Kyaukpadaung

Management and maintenance: maintain the terrace embankment and the stone works whenever necessary. If necessary, treat upper portions of the catchment with other conservation measures (cutoff drain, checkdams, stone bunds, trenches, etc.). Adjust the work norm based on the type of modification applied to original design.

Integration requirements: protect the terrace embankment from cattle interference for the first season and stabilize the embankment with vegetation (see stabilization). Apply compost to the area, improve crop rotation, mulch part of crop residues, etc. If possible, apply deep ripping to the field (beneficial to break impervious plough pans).

Limitations: this design is not applicable to areas having slopes > 3%. In this case apply options for soil bunds or stone bunds.

Training requirements: same as for soil bunds reinforced with stone keys and provided with checkdams.

DEEP TILLAGE AND TIE RIDGING

Definition and scope

The two measures mentioned here as possible supplementary techniques to support the growth of crops in combination with physical structures such as soil/stone bunds and bench terraces.

Deep tillage is meant to increase the available moisture into the soil profile by increasing the rooting depth. Crust and light hard pans are broken and thus temporarily increase infiltration. Besides, plant roots can probe deeper into the soil and reach additional water and nutrients. When left decaying into the soil, deep tap roots can increase porosity and then reduce runoff. Its application is mainly in mechanized agriculture and seldom at the scale of the small subsistence farmers unless some forms of cooperation takes place. with a group of farmers agreeing to hire a tractor. Two main tillage operations are suggested:

Deep ploughing, which is a mechanical operation meant to improve moisture storage conditions temporarily. Consequently runoff may be reduced and crops cover the soil faster. However, deep ploughing in many dry lands soils, tend to pulverize the soil aggregates and increase its susceptibility to splash erosion (increase of the suspending load of runoff). The effect of tillage on soil erosion vary with the type of soil and the time of its application. the type of crops planted and the management of crop residues.

Ripping and subsoiling, integrated with soil or stone bunds, can be particularly beneficial to increase the porosity of the soil but specially to break the various pans (labour pan, illuviated clay pan, etc.) which are reducing permeability. The expected benefits are: substantial increase of infiltration rates and water availability to plants, particularly in the short term, and increase mass of soil and nutrients for the roots to probe.

Ridging and Tie-ridging are manipulations of the soil surface meant to increase surface roughness, water storage and reduce runoff. First furrows are made and then dammed with ties or small mounds at regular intervals, based on crop stands and requirements. Tie-ridging is widely applied in several arid and semi-arid areas and effects on crop yields are generally good. However there may be waterlogging problems for waterlogged sensitive crops. Good responses are commonly reported for sorghum, millet and maize.

Technical specifications

Deep ploughing:

Animal traction: It is difficult and needs considerable draught power that is scarce in dry zones. Implements seldom reach 0.5'-1' depth and are not effective to significantly increase infiltration.

Mechanization: At least a 75-90HP tractor is required for reaching a 1.5'-2' depth. Tillage with disc plough is not advocated since it pulverizes the soil considerably, exposing it to wind and splash erosion, sun radiation and mineralization of organic matter and reduction of the cohesiveness of soil particles. Other type of plough and tillers penetrate deeper and allow the organic matter to be turned in but tend to create a hard pan in the long term and bring to the surface soil from deeper layers, which is poorer in humus and thus more susceptible to detachment by rainfall impact. In this respect deep ploughing is always a controversial issue whose pro and cons should be determined based upon the soil type, slope, cropping patterns and management of crop residues. In general, it has been observed (Charreau, 1969) that if all crop residues are ploughed in during a rough and deep tillage at the end of the cropping cycle, prior to the long dry season, structural stability and infiltration are both improved, thus reducing erosion problems.

The **slope** is a limiting factor since tillage operations along the contours become risky above 20% slope. **Soil depth and texture** are important to determine which depth the tillage operation will reach and thus its effectiveness. Heavy clays are difficult to plough. Similar are thick hard pans close to the surface.

Ripping and Subsoiling:

Animal drawn ripper: an animal-drawn ripper is locally manufactured by the Agriculture Mechanization Division, CARI, Yezin. It is meant to reach 2' depth but under normal conditions 1' and 1.5' are reached for heavy and light soils respectively. They can break only light (few inches) hard pans (mostly plough pans) and are seen as rather effective under such limited conditions. However, in most parts of the Dry Zone the scarcity of draught power would be a major limitation to this practice (animals are sparingly used for ploughing and other crop operations only). Additional testing, training and dissemination are needed.

Mechanized ripping: as a general practical rule, tractors of 90-120 HP are necessary to pull a one (3-3.5') tooth or three (2-2.5') tooth ripper respectively. In Myanmar, smaller rippers should be tried to accommodate the 75 HP tractors commonly available. However, it is likely that at a 3' depth in most sandy soils of Magway can be reached and as well as a 2' depth in the remaining main soil types, excluding areas with high stoniness or very shallow soils above rocky parent material. Depending from the type of soil ànd the thickness of hard pans, the optimum depth for ripping may decrease or increase accordingly. Deep ripping at 3' interval along the contours is considerably more effective than deep ploughing. The ripper breaks the hard pan (implode) laterally and vertically without turning the soil and exposing it to radiation and splashing erosion. Without further ploughing and combined with mulching (conservation tillage) ripping is very effective to reduce erosion and increase infiltration. Therefore it is an excellent option to improve fallow lands and lands affected by hard pans close to the surface. On cultivated lands, ripping make subsequent ploughing operations easier, increase infiltration of first erosive showers, reduce runoff and thus decrease erosion risks, increase development of the root zone, access to water and nutrients, thus enhance crop productivity.

Tie-ridging cannot take place on ***slopes*** >3% or, in case of sloping lands, only on bench terraces. ***Deep soils with good permeability*** are suitable to provide sufficient moisture storage and absorb quickly the contained flood water. The ties should be lower in height than the furrows so that, in case of excess runoff, the ties fail along the furrow before the ridges overtop in the direction of the slope.

Integration requirements:

Deep ploughing should be followed by contour ploughing, stubble mulching, surface mulching and other biological measures meant to improve soil structure and permeability on a long term basis. Bunding is always recommended whenever mechanized ploughing is taking place, to control possible erosion which may occur as a consequence of the negative effect ploughing has on the soil aggregates. However, bunds may hamper mechanized operations, therefore access to the fields (laterally) should be taking into consideration.

Ripping beside the same recommendations as above, should be combined with sowing of crops or pasture legume (ley) with deep and nitrogen-fixing tap roots (pigeon peas, stylosanthes, etc.) along the ripped lines which will increase the positive effect of ripping. The decay of roots within the cracked lines would delay the reformation of the hard pan for a few years. Therefore, the hiring of a tractor by a group of farmers for such kind of operation may be more convenient.

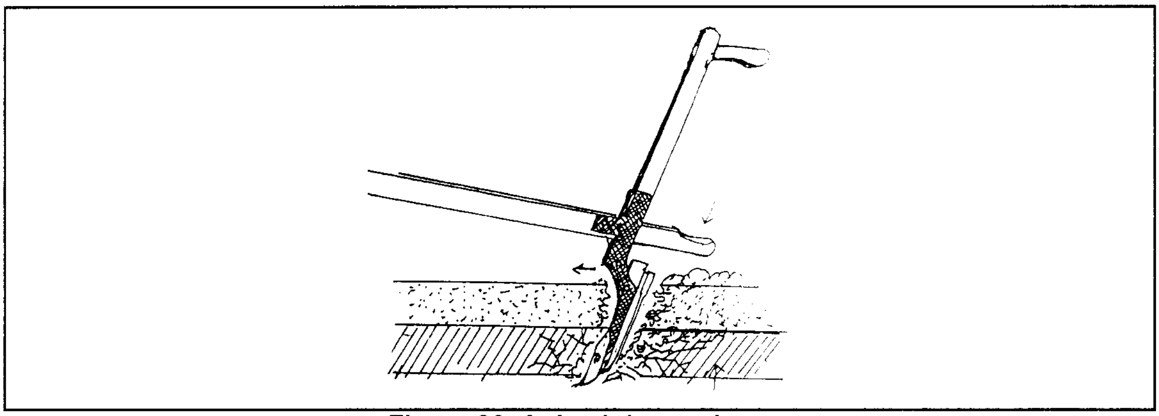


Figure 28 Animal drawn ripper

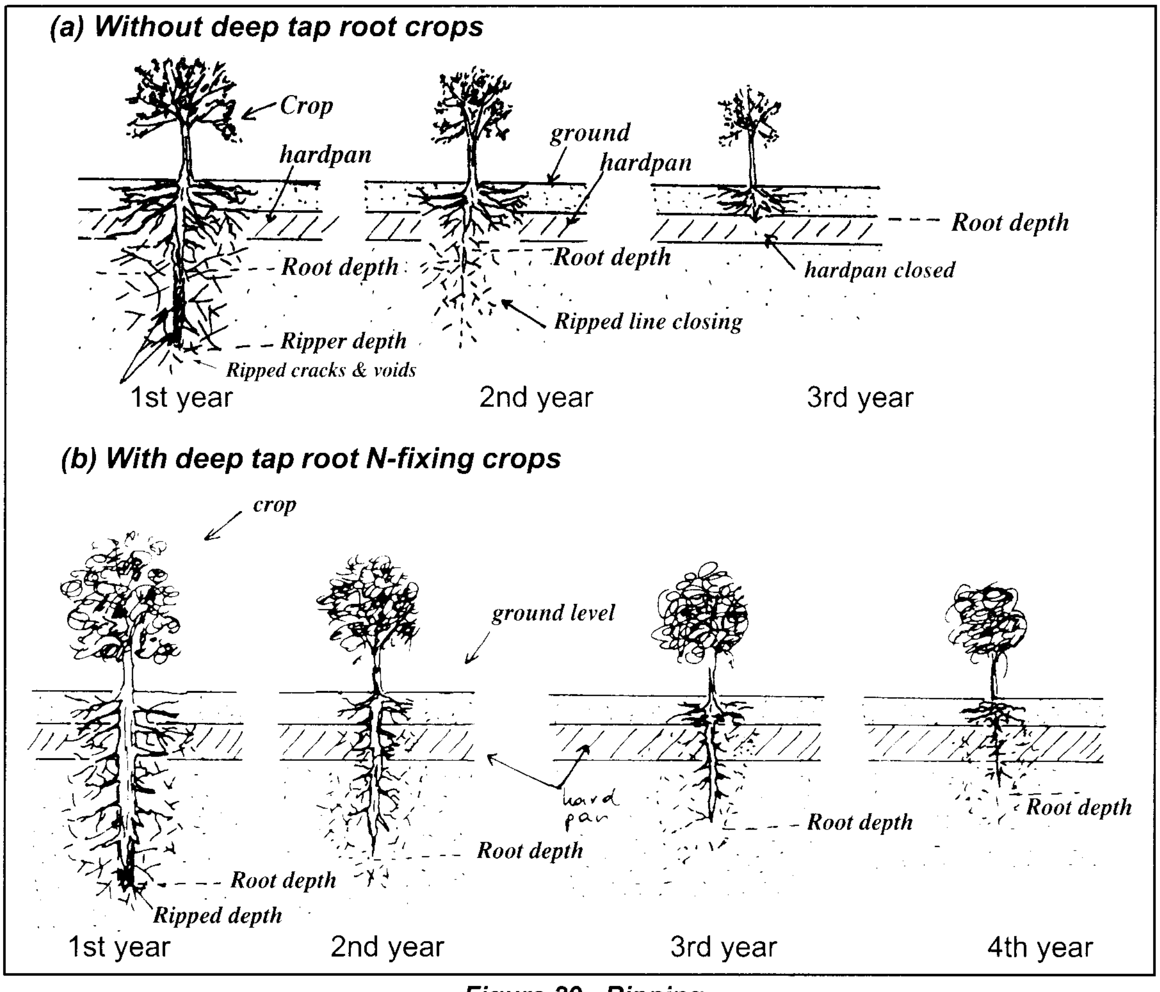


Figure 29 Ripping

Tie-ridging is most effective if practiced in between bunds to avoid risks of overtopping and uncontrolled runoff. Other biological measures such as mulching and composting are recommended.

Inputs requirements and limitations:

Deep ploughing requires mechanical traction which is expensive and thus applicable only under specific circumstances and through the right guidance for optimum utilization.

Ripping is also expensive but have a long lasting effect, specially if supplemented with mulching, compost application and proper cropping practices. A possible limitation is the availability of rippers and tractors provided with sufficient HP.

Tie-ridging is mostly done in mechanized agriculture. Some implements have been developed but require considerable draught power. Within the context of the Dry Zone, making furrows is relatively easier by oxen but making ties is laborious and can be made only by hand, and thus is justified only if crops yields are high. Besides, tie-ridging is an operation which is supposed to take place after the first effective rains, i.e. during sowing time, when most farmers need their animals to sow crops and, under dry zone conditions, when this operation should be completed as quickly as possible to take advantage of the moisture.

Management and Maintenance: Tie-ridges are normally maintained during regular farm operations (weeding, breaking surface crusts, etc.).

Training requirements: Training to field staff and farmers is necessary to consider the pro and cons of the above measures and the required integration requirements. Training of tractor operators in ripping and ploughing along the contours and proper use of ripper may be also necessary.

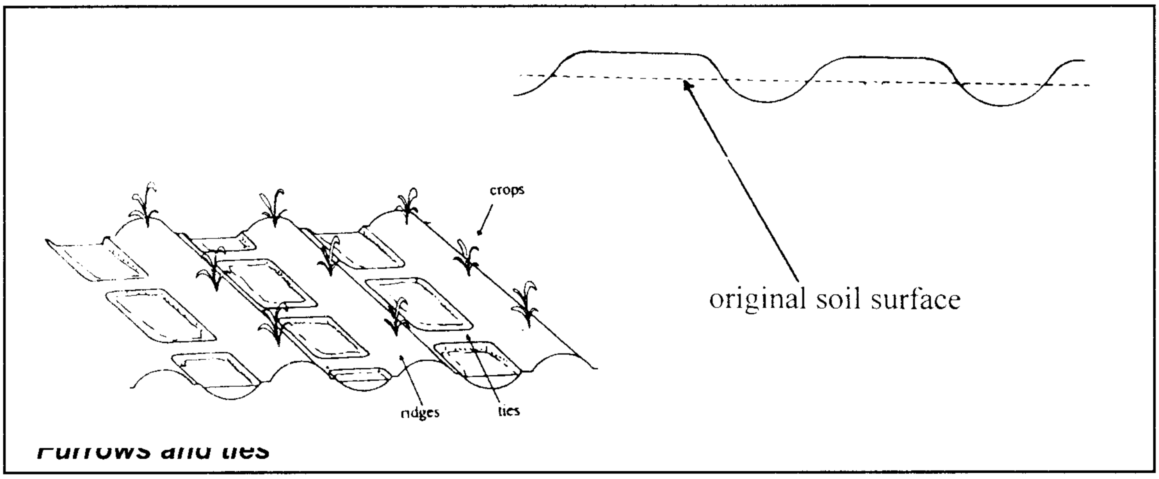


Figure 30 Tie-ridging


Example of tie-ridges short after the rains (Zimbawe)

B. INCREASING WATER AVAILABILITY

STONE FACED/SOIL OR STONE BUNDS WITH RUN-OFF/RUN-ON AREAS

Definition and scope

In the Dry Zone, several potential sites for the application of rainfall multiplier system are observed. They are often marginal areas with low productivity, shallow soils, often affected by surface crusts and low water infiltration rates, with slope ranging between 1 to 5%. They border cultivated fields or gully sides, are mostly used for temporary grazing and/or cultivated during years of abundant rainfall. These areas can be partially converted into productive uses, whether for food or fodder crops, using stone faced/soil or stone bunds with runoff/ runon areas. The runoff area is intended (microcatchment) to supply additional water into a run-on area (cultivated area). **The scope is to increase production levels in one portion of the total area or to introduce food or forage crops with higher water requirements that otherwise would not grow without additional moisture.** Both runoff and runon areas are included within the bunds.

Technical specifications

Slope range and type of soils: Runoff/runon systems are recommended for slopes < 5% and minimum workable soil depth above hardpan of 50 cm (1.5') or more. Possibly, hardpans should be ripped before applying the rainfall multiplier system. If not, choose shallow root crops.

Runoff/run-on ratio: Ratio of the area yielding runoff (catchment area) and the area receiving runoff (cultivated area) varies according to:

- The variation of soils (texture, infiltration etc.). The deeper the soil and its infiltration capacity the higher the water storage capacity.
- The crop water requirements.
- Suggested ratios are 0.5-1:1 and 1.5:1 (0.5-1.5 run-off/catchment area and 1 run-on/ cultivated areas).
- The type of bunds. In case of soil bunds, without stone reinforcement, ratio should not be higher than 0.5-1:1.

Size of the area delimited by two bunds: Small catchments will harvest runoff even from shorter storms. Their gathering time is shorter and water have less time to infiltrate in the runoff area before its reaches the cultivated one. A problem might be the high number of bunds required if the areas are too small and the reduced area for cultivation. In large catchment areas, water can stagnate, have more time to infiltrate and evaporate before reaching the cultivated part. Besides, the layout of the bunds may be difficult and risky (breakage) in an heterogeneous terrain (gradient and direction of slopes, infiltration, soil depth variations etc.). Concluding, the size must be established according to local testing, soil types and agricultural practices. An example of dimensions that could be applicable and tested under Myanmar conditions is given in figures 31 and 32.

Layout of bunds: bunds should be level and wing up laterally in order to evacuate excess water. **The layout should be unconditionally and unmistakably along the contours.** Depression points are to be avoided and/or bunds are reduced in size and oriented in different directions based on these slope.

Construction stages and dimensions: Before designing and constructing the level bunds, **a cutoff drain may be required above the treated area to divert and safely dispose excess runoff (see cutoff drain).** However, if bunds are applied in almost flat or topped-hills areas (for example portion of plains, plateau etc.) or below bunded areas, there is no need for a cutoff drain.

The level bunds are either soil, stone faced/soil bunds or stone bunds.

- **For soil bunds,** range of slopes should be < 3%, and soils of sufficient depth (>50-100cm). The bund should be well stabilized with grass and tree/shrubs.
- **For stone bunds,** besides a strong and large foundation, sealing of the stones is important to reduce the flow of runoff through the bund and facilitate the growth of grass. On completion of the stone work, a layer of soil should be placed on top of the bund.
- **The stone faced soil bunds** should be very well compacted and stone walls should be placed on both sides of the bund. The top of the bund is also planted with dry resistant grass species.

The **height of the bunds** should be at least 50-75 cm (1.5-2.5'), **length** from 25 to 100 m (80-330'), **bottom width** 1.5-2 m (5-6.5') and **top width** 30-50 cm (1-1.5').

The bund has wings as long as the width of the cultivated area (10 meters (33') in the example).

Distance between bunds should not exceed 15 to 20 meters (50-65') within this range of slopes. For soil bunds, the distance should not exceed 10-15 meters.

Lateral distance between two bunds is 2-5 meters (6-15') and protected with lines of stones (from the wing of one bund to the adjacent one). This is needed to evacuate excess runoff and avoid overtopping of the bund frontal embankment. In dry areas the probability of heavy and destructive showers is an element that must be taken into consideration before the construction of the measure as it may happen that the bund structure can be overtopped and damaged at its bottom by the excess water (water fall effect). To avoid this, the **lateral wings should have a decreasing height** in order to be the first to evacuate excess runoff.

Very important during layout is that bunds should be staggered alternatively. As a precaution, the bottom of the front side of the bund (in case of stone faced/soil bunds) should be paved with two lines of stones along the entire length of the bund (see figure 32). This is called a **downstream apron.**

Maintenance of the structure should be always ensured during the cropping season. You may remove vegetation from the runoff area and compact the soil surface to increase runoff from the catchment area. However, these practices are not commonly used.

Provision of spillways may be also required in addition to the wings (for higher ratio, low infiltration, aggressive rainfall, etc.), particularly in case of soil bunds.

Integration requirements: same as for soil/stone bunds

Ridging of the run-on (cultivated area) areas along the contours is recommended for an even distribution of moisture. Every ridge along the contours should be interrupted to allow water to pass through into the next furrow (see figure32). The labour input for ridging is considerable and should be estimated but in dry areas this operation is normally worth the effort and cost-effective.

Dry resistant trees/shrubs (Acacia species, Aloe sp., Agave sp. etc.) should be planted every 2-5 (6-15') meters along the ditch/berm of the bund.

Work norm: same as for stone faced/soil bunds. Labor costs increase for tie-ridging and possibly ripping or subsoiling.

Inputs requirements: same as for soil/stone bunds + costs for ripping or subsoiling if required. Ridging is a farmers responsibility.

Training requirements: These methods should first be demonstrated at small scale and different ratio tried before finalizing recommendations. Thereafter, training of farmers should take place, with particular emphasis on layout, construction of wings and soil surface management (tie-ridging, mulching, etc.).

Limitations refer to the labour availability for construction and maintenance.

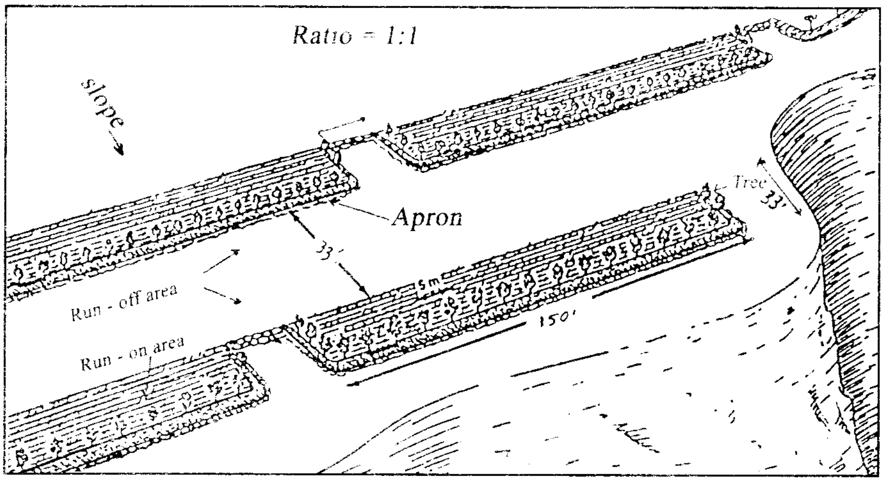


Figure 31 Rainfall multiplier system for crop production

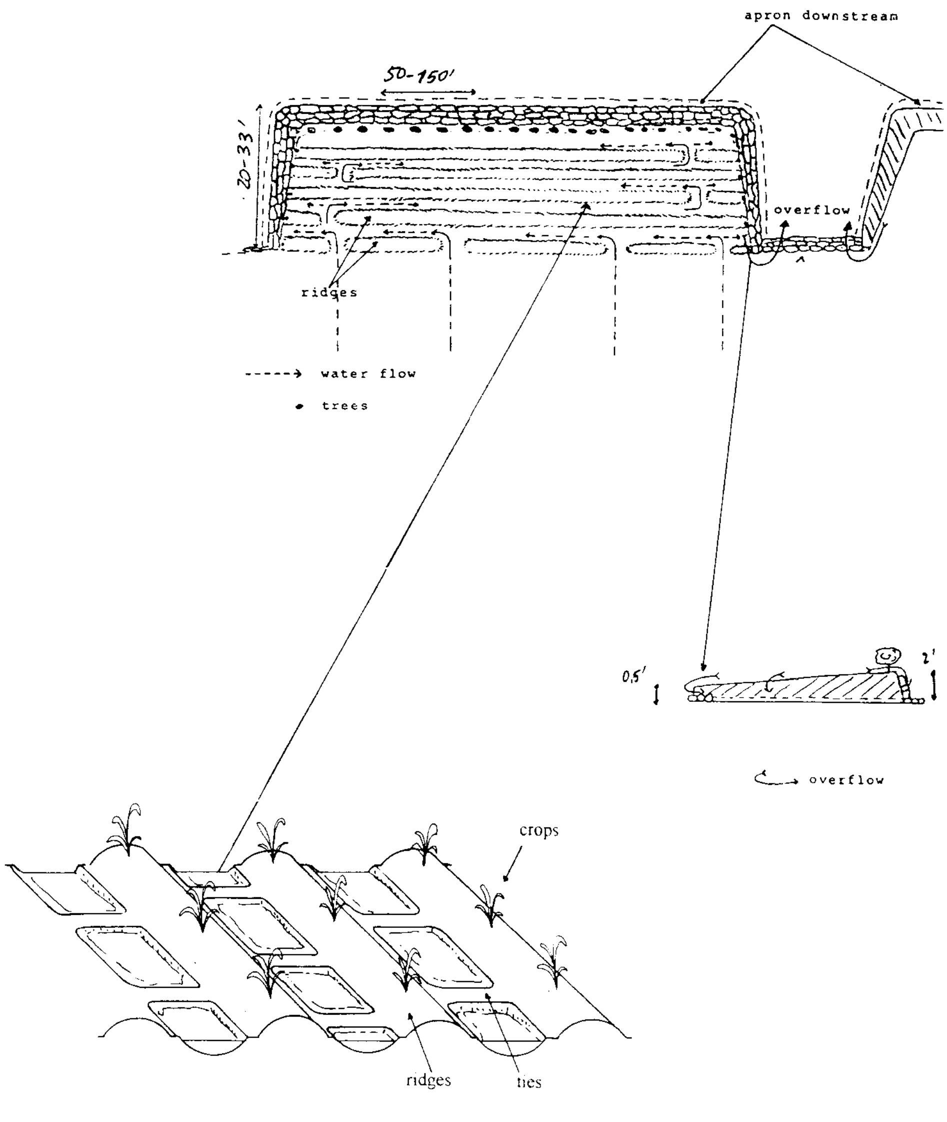


Figure 32 Aerial and cross section views

Example of rainfall multiplier systems for crop production in Niger - Keita (Source - Renato Carucci)

(1) Before the rains (notice water - clear spots accumulated along bunds)

(2) After the rains (dark areas are crops)

CONSERVATION BENCH TERRACES WITH RUNOFF/RUNON AREAS

Definition and scope

The conservation terraces described here could be intermittent or continuous terraces, depending on the slope.

Intermittent terraces are set out at intervals which are used as runoff areas. These terraces are suitable for areas with low precipitation but with moderate rainfall intensities (rare). Part of the land surface is used as a catchment to provide additional runoff onto level terraces (Figure 33 and 34).

Continuous terraces are partially left uncultivated to supply additional moisture onto the cropped area. The level of the terrace has a gentle gradient (0.25-3%) towards the cropped area (inwards or outwards).

Technical specifications

(i) Intermittent terraces

Deep soils and good permeability are required so that the flood water can be absorbed quickly. ***Slopes*** range from 1-5%. At the edge of the terrace a small stone embankment should be constructed, of 40-60 cm width x 20-30 cm height. The stone embankment is linked to the terrace stone riser (wall) which should be well constructed and properly inclined.

The suggested run-off/run-on ratio is 1:1, or 2:1 in low rainfall areas. Width of the terrace ranges from 10 to 30 meters up to slopes of 5%.

Precise layout and leveling is required. Width of the terraces are min. 10 meters and max. 30 meters.

Construction phases and dimensions:

The following steps have already been explained for bench terrace construction

If there is a risk that run-off from the catchment area will be greater than the absorption of the cultivated area, outlets at the far end of the terrace side (plus a waterway) should be constructed for evacuation of excess water (Figure 34). **In this case the height of the bund at the edge of the terrace should be high enough to avoid overtopping,** possible erosion downstream and breakage of structures. Instead, water should discharge laterally, through a system of ties and small spillways. The water should discharge into a natural or artificial waterway (the outlet should be half the height of the bund).

Work norms and inputs requirements: This measure is **labour intensive and time consuming**. But where these two factors are not a constraint and the land taken out of production by the run-off area is not a problem for the users (areas not yet under cultivation), the measure can be effectively tried.

Integration requirements, maintenance and training: same as for soil, stone faced/soil bunds with runoff/runon areas and bench terrace construction above. You may remove vegetation from the runoff area and then compact the soil to increase runoff from the catchment area (not common - expensive).

A **cutoff drain** should be constructed above the treated area if necessary.

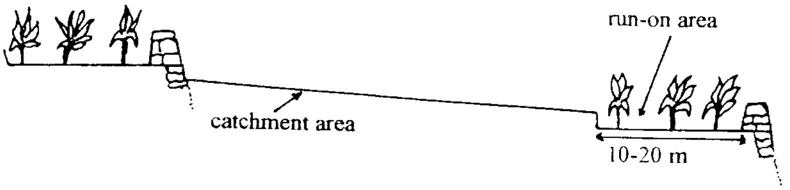


Figure 33 Example of intermittent bench terrace

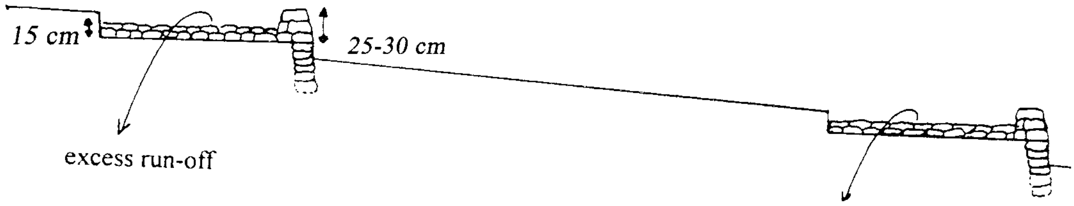


Figure 34 The intermittent terrace discharging excess runoff sideways

(ii) Continuous bench terraces with runoff / run-on areas

The technical specifications are similar to the normal bench terraces. For instance the vertical interval is two and an half times the workable soil depth. The portion of the bench left uncultivated is shaped with a gentle slope (0.2-0.4%) towards the cultivated portion which is kept level.

However, a stone **embankment is required at the edge of the terrace as an extension of the wall riser (inclined)**, its width 30-50 cm and height 30-40 cm.

Precise layout and leveling of the cultivated area is necessary.

The plantation of crops should be limited to two thirds of the total surface to avoid excess runoff within terrace and overtopping. Then, the runoff/runon area ratio should not be higher than 0.5:1.

If there is a risk that runoff in the cultivated area will not be entirely absorbed, **outlets should be provided at the end of the terraces, for discharge into waterways** (stone paved). In this case the height of the stone embankment at the edge of the terrace should be higher than the outlet laterally constructed, so that water will overflow through the outlet and not over the terrace embankment/riser. It is suggested that the outlet device should be half the height of the terrace upper embankment, i.e. 15-20 cm. A spillway can also be placed along the embankment.

The wall riser should be well constructed using large flat stones and inclined inwards to the slope.

Careful and continuous maintenance: You may remove vegetation from runoff area and compact the soil to increase runoff from catchment area. However, these practices are not commonly used.

Work norms, inputs, integration, limitations requirements as for bench terraces. + add cutoff drain constructed above the area if necessary.

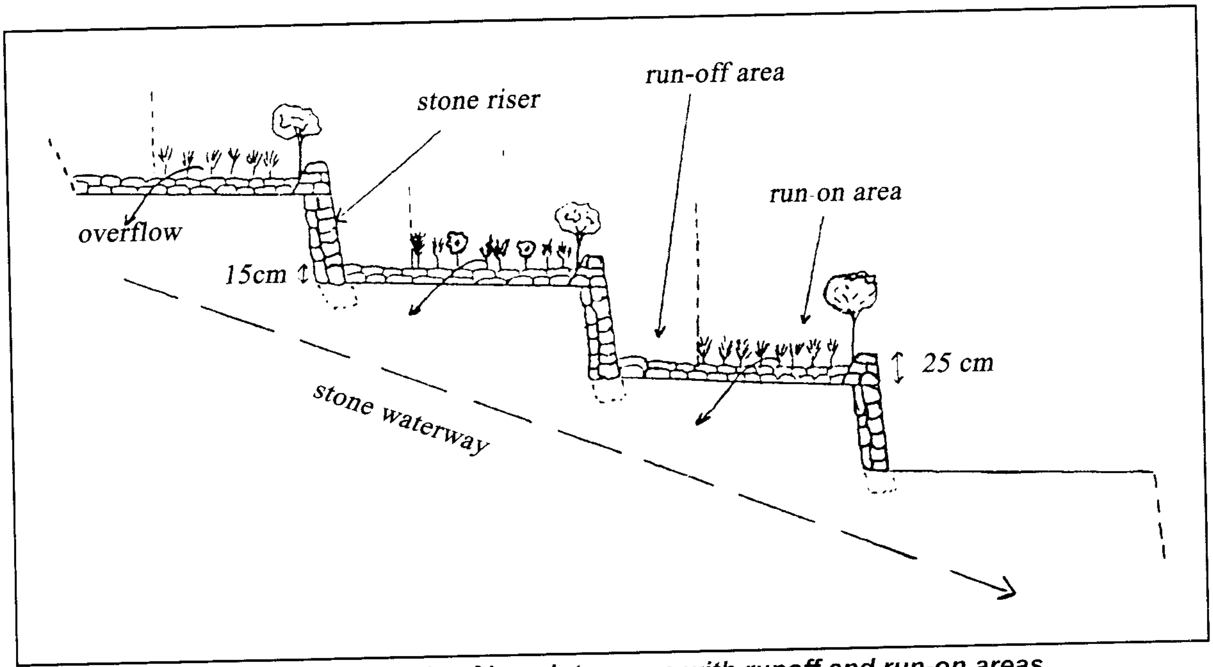


Figure 35 Example of bench terraces with runoff and run-on areas

CONTOUR FURROWS IN BETWEEN SOIL AND STONE FACED AND STONE LEVEL BUNDS

Definition and scope

In between physical structures such as soil/stone faced and stone bunds, the soil surface is shaped in various ways to increase and collect moisture around the plants and thus increase yields. This system is similar to tie-ridging but the surface modifications are more important here. The technique is also applicable in already cultivated fields treated with bunds. The land can be shaped either by using oxen pulling tool bars or by hand. It is a labor intensive work and need farmers properly trained and interested to undertake this task.

Technical specifications

Slope: The measure is suitable for slopes less than 3% and with soil depth > 100 cm. Soils should be of medium texture, with good infiltration and storage capacity. Heavy clays or sandy soils are not suitable.

Layout and construction phases: Construct stone or stone faced/soil bunds as indicated in the above sections. The bunds protect the area from excess run-off, maximize water retention and avoid overflow. Shape the land as shown in figure 36. The top height of the mounds should not exceed 0.5'. The collector area and the cultivated area may have different spacing according to the type of crops and their water requirements, and rainfall patterns (amount and intensity). Test this technique in small plots before a wider application. In addition to the furrows, low cross ties (0.25') can be used to obtain better water distribution and reduce the risk of accidental and uncontrolled run-off if a line collapses within the area (see tie-ridging).

Integration requirements: same as for tie-ridging. Mulching of crop residues in the cropped area is recommended to increase the infiltration capacity of the soil and fertility levels.
Management and maintenance requirements: same as for tie ridging.

Work norms, inputs and materials requirements: same as for tie-ridging. In this case, special oxen pulled tool bars or levelers (traditionally available) can be used. Refinements will be done by hand using hoes.

Training requirements: train farmers using small scale demonstrations.

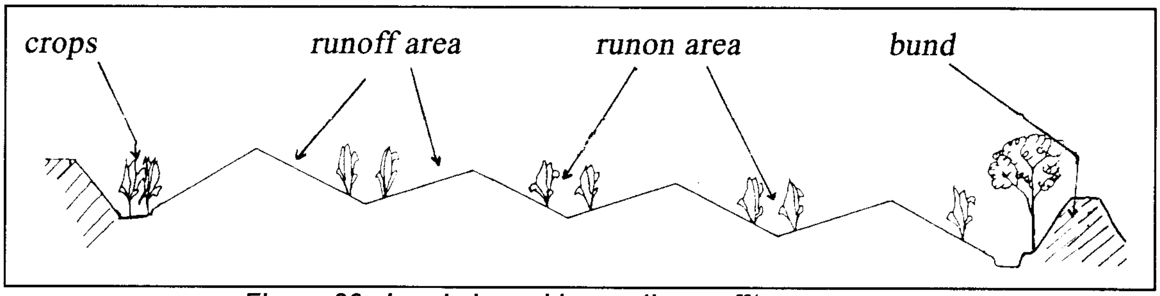


Figure 36 Land shaped in small run-off/run-on areas

THE ZAÏ AND PLANTING PIT SYSTEM

Definition and scope

The word Za means pits (literally water pocket) and its originates from Mali and Burkina Faso (West Africa), countries where **a system of small pits dug along approximate contours allows the cultivation of crops on degraded lands.**

The za pits **restore degraded (crusted, hard, compacted and poorly structured soils) lands,** thus increasing the land available for cultivation. It is a simple technique that landless or oxen-less can practice because it requires only manual labour.

The zaï system improves the soil structure (increase of organic matter content, microorganisms activity, aeration, circulation of nutrients and water into the soil, etc.) and thus infiltration. Consequently, they protect the soil from further erosion and conserve & store water and nutrients. Long periods of fallow may be shortened by the za system, returning the land to crops earlier and in better conditions of fertility and moisture storage.

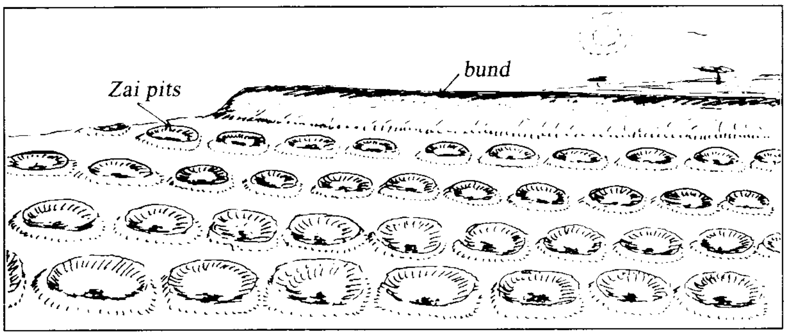


Figure 37 Zaï pits

Technical specifications

Type of soil and slope: on degraded hard crusted, shallow and compacted, nutrient depleted gentle sloping lands (slopes < 5%). They could be implemented:

- *to treat abandoned lands that oxen-less farmers wish to restore for growing crops and to improve fallow lands,*
- *to rehabilitate degraded gentle sloping lands near gully sides and,*
- *to make productive small plateaus on top of degraded hillsides.*

Layout, dimensions and construction phases: Start from the **top of the field.** The Za are series of pits dug following approximate contours. However, for better orientation mark few contour lines at regular intervals of 50' by using the line level.

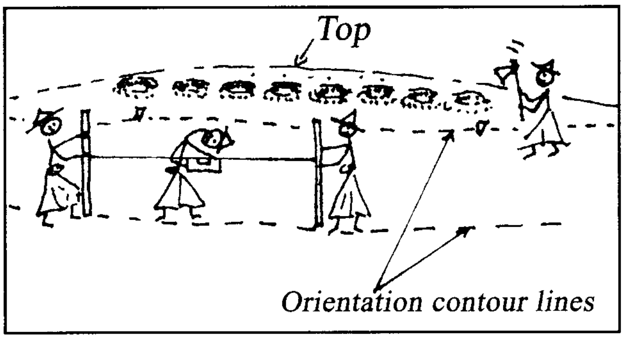


Figure 38 Layout of Zaï

Construction starts after the rainy season, by the end of October - November (1st cycle) when some residual moisture facilitates the workability of the soil. Use hoe, pick ax, shovel and occasionally crow bars to dig the pits. Start by digging the first line of pits following approximate contours between the marked contour lines.

The pit may have various sizes, 1-1.5' diameter x 6-9" deep. Spacing apart two za & pits within each line is 1-1.5'. Pile the excavated soil downwards.

Proceed downwards the slope and dig the second line of Za and pits staggered against the first line. Spacing between the Za and pit lines is 2'-2.5'.

After construction, apply one full spade of FMY or compost to each pit.

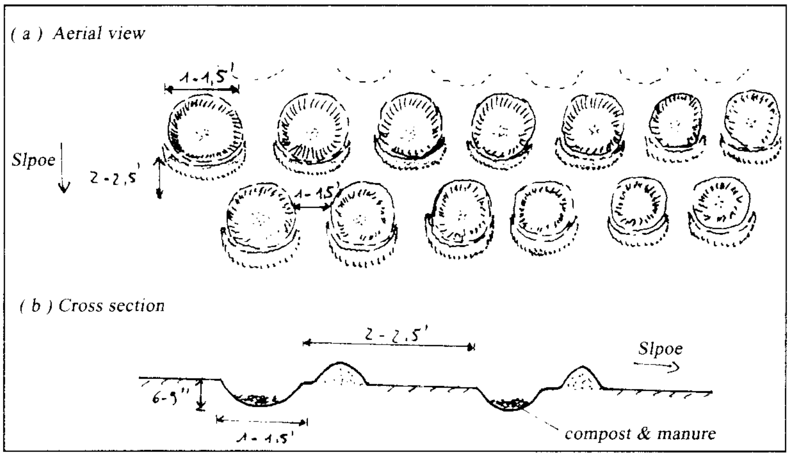


Figure 39 Zaï pits construction

During the dry season, the wind will bring additional leaves and residues into the pits. **Therefore, the different microorganisms, ants or termites will start recycling organic matter up and down into the soil profile, loosening and improving the structure all along.**

After the first rains, Zaï pits are sown with sorghum or millet (first season). Za pits harvest water and conserve soil. Soil moisture further improves the biological life and conditioning of the soil structure.

At the end of the growing season, sorghum & millet stocks are harvested by **cutting them 2'-3' high from ground level.** The remaining stock is manually broken and thrown into the pit. During the second dry season the stalks will be decomposed and pulverized by the termites, ants and other organisms.

During the second dry season, another round of Zaï pits can be dug in between the first year lines following the same procedures as above (2nd cycle).

During the second rainy season, plant legumes inoculated with rizhobium on the pits dug on the 1st cycle. The second cycle pits are sown with sorghum or millet.

By the end of the second rainy season, the whole area is expected to be rehabilitated and easy to cultivate by either bullocks or manually.

After the two cropping seasons (cycles) using sorghum or millet you can switch to other crops (legume, sunflower) but always remembering to leave some or most crop residues into the soil.

1st CYCLE				2nd CYCLE			
Oct-Nov	Nov-Dec	June-Aug	Oct-Dec	Nov-Jan	Jan	June-Aug	Oct-Dec
Dig Za	Apply manure & compost	Sowing sorghum millet	Harvest + stalks mulching into pits	Dig za between lines	Apply compost& manure	Sowing sorghum millet + legumes on 1st cycle pits	Harvest + stalks mulching into pits

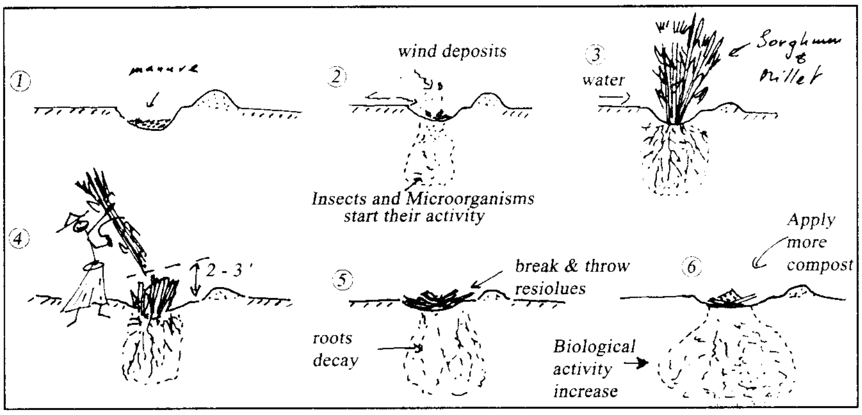


Figure 40 Construction & management sequence (one cycle)

Work norm: the rough estimation of number of za pits per acre range from maximum 13,200 to minimum 6,400 pits based upon spacing and size. One person can dig 60-100 pits per day (depending on soil types). It should be noted that the investment per acre during two cycles of za should not be seen only in relation to the yields of sorghum or millet but to the value of the land after the treatment.

Inputs requirements: mostly manual labour and tools such as crow bars, pick axes and shovels. Compost or FYM should be available (minimum 1-2Tons/acre).

Integration requirements: Checking of the quality of incorporated stalks (pest free) and carrying out of proper pest control and management if necessary. Preparation of compost to provide additional fertility (see compost making). To avoid excess runoff damage to za plots (chain effect), construction of contour bunds every 20-30 za lines is recommended, particularly when the occurrence of destructive showers is high. Once the plot is rehabilitated a proper rotation and organic fertilization should take place.

Training requirements: construction of za pits is easy and do not need particular skills and training, except to orient the pits along approximate contours and staggered podition. Continuous follow-up is required to ensure the proper management of the za pits.

Limitations: The Za system is labour intensive. It is then applicable where shortage of cropland is severe and labour is available and seen as cost effective investment. Za system is not recommended on slopes > 5% because of high risks of breakage. They are also not recommended on sodic soils and very sandy soils (structural stability, limited biological activity). Za pits require farm yard manure which may not be available by the small farmers and the landless, and thus need to be purchased, increasing costs. Require maintenance for the several years.

SEDIMENT STORAGE AND OVERFLOW EARTH DAMS (SS DAMS) IN GULLIES

Definition and scope

For practical purposes this measure is named SS dam. **These structures are small earth dams constructed across large or medium size gullies, for sediment trapping, water collection and diversion and overflow of excess runoff.** This rainfall multiplier systems is a typical external catchment system where runoff is generated by the catchment located above the gully. The structures are often constructed in series.

The space behind these structures is rapidly converted into fertile and productive fields, in several cases even paddies. The farmers skillfully accelerate sedimentation of the dam by reshaping its borders and leveling the soil. The overflow spills into the next area and so forth. **Provided the construction standards are respected and the spillway is properly designed, the SS dam is a very effective and highly valued (by farmers) SWC measure.** The SS dams are also important means to convert unproductive lands such as gullies into fertile fields and thus decrease the encroachment of forest areas and steep slopes for cultivation. The value of one acre of land behind an SS dam is at least twice or more times (specially if paddies are grown) the value of a normal upland field.

SS dams are a gully control mechanism, and thus have a **beneficial influence in regulating water regimes and protecting downstream areas from excess runoff.** However, as per the conditions of the sub-watershed area above the gully, this measure may be supplemented by different additional SWC activities (bunds, trenches, etc.).

Technical specifications

Site selection: The site should not be selected in forest areas. Farmers may see it as an opportunity to encroach and then cut trees to allow space for the formation of a cropped field.

The site should not be below very large catchments, i.e. generally less than 100-200 acres maximum, because of the increased costs required to construct larger and reinforced structures able to accommodate high peak runoff discharges.

The site should allow the maximum formation of a cropped field area. Wide portions of a given gully are preferred to narrow and deep portions.

For every site, check whether there is a suitable side for constructing the spillway. Sodic and soft sandy soils must be avoided. Stony areas, limestones, very hard pans and soft rocks are instead recommended.

The type of soil: for the construction of the SS dam soils should not be:

- too loose (sandy),
- heavy expandable clays such as montmorillonites,
- sodic (dispersed when wetted).

Therefore, soils should have:

- a medium texture,
- a poor organic matter content,
- the tendency to compact and seal easily.

It is not always possible to find best soil type conditions and, except for sodic, heavy expandable clays and very sandy soils, others which do not fulfill these characteristics should be considered suitable for SS dams, particularly where some textural problems may be overcome by increased dimensions of the structure and strong reinforcements of the dam sides.

Layout, Dimensions and Construction phases:

Layout follows the site selection and is carried out using an auger or soil profile cuttings to sample soil/parent material conditions in order to decide best placement.

⇨ With a meter tape and a graduated long pole (20') measure the desired base and bottom length, height and consequent base and top width of the structure.

⇨ Proceed to select the best emplacement of the spillway. Estimate spillway construction standards (see below) including gradient and length.

⇨ The spillway may be supplemented with drop structures and an apron at the tip of its outlet into the gully.

The dimensions of the structure embankment are selected based on the area of the catchment, the width of the gully and specially its depth.

The following criteria are applied for the estimation of the dimensions of the structure:

H = height of the structure
TW = top width
TL = top length
BW = bottom width
BL = bottom length

H < 5' H:BW (Height: Bottom Width ratio) is 1:2 → TW = 5'
H = 5-10' H:BW (Height: Bottom Width ratio) is 1:2.5 → TW = 7.5'
H = 10-15' H:BW (Height: Bottom Width ratio) is 1:3 → TW = 10'

Measurement of the volume of earth/stone work required: The volume of earth/stone works should be estimated for:

(1) The SS dam embankment (V1)

$$\textbf{V1} = \textbf{Volume of earth work} = \frac{\textbf{H x (TW+BW) x (TL+BL)}}{\textbf{4}}$$

The above is a simplified but acceptable formula to estimate the volume of earth/stone work for a trapezoidal shaped SS dam.

(2) The spillway (V2)

V2 = Length of spillway (generally equivalent to BW) x base width of spillway x total depth of channel (see procedure below or table 2 in Annex 3)

V1 + V2 = Total Volume of earth/stone work (including foundation)

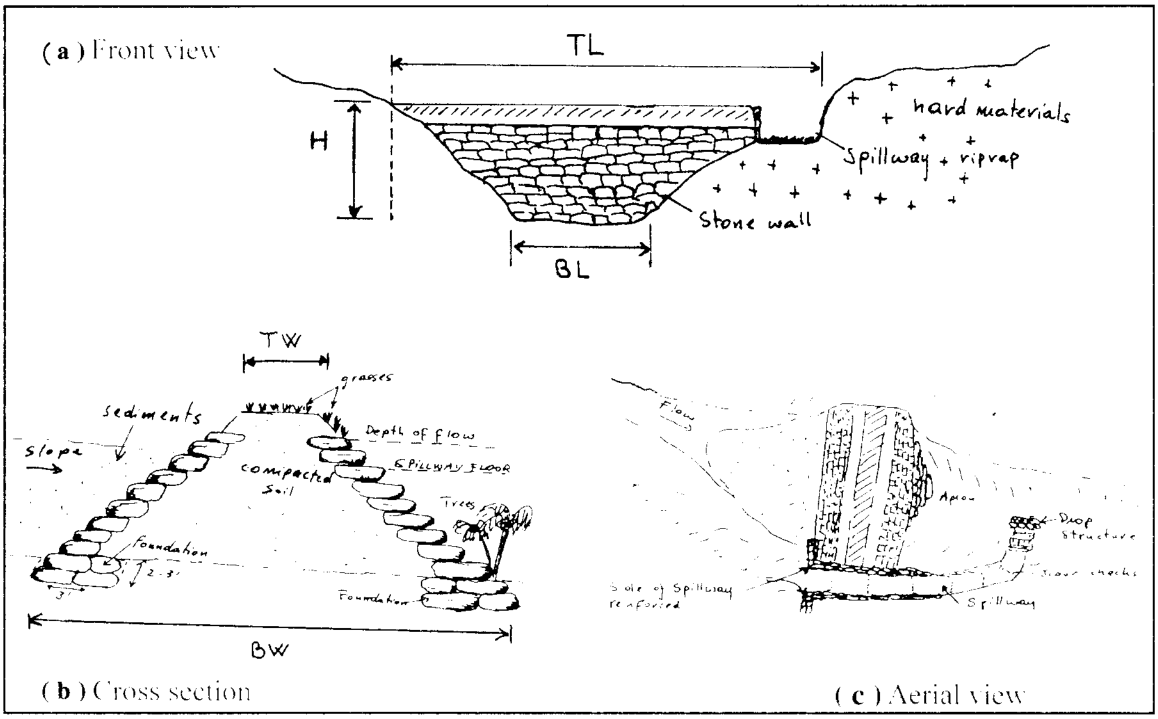


Figure 41 A Sedimentation storage & Overflow Dam

Site selection and layout of SS dam (Thee Kone - Kyaukpadaung)

Construction standards and phases: Farmers should use bullocks, ploughs and traditional levelers to carry out this task. Tractors and bulldozers may facilitate the work but may not be easily available, are expensive and accessibility to gully bottoms is often difficult.

⇨ The construction starts with **scraping and removing grass and vegetation** from the whole bottom and sides of the gully where the dam embankment is to be constructed. This is to ensure **structural continuity** between the bottom and sides of the gully and the dam embankment.

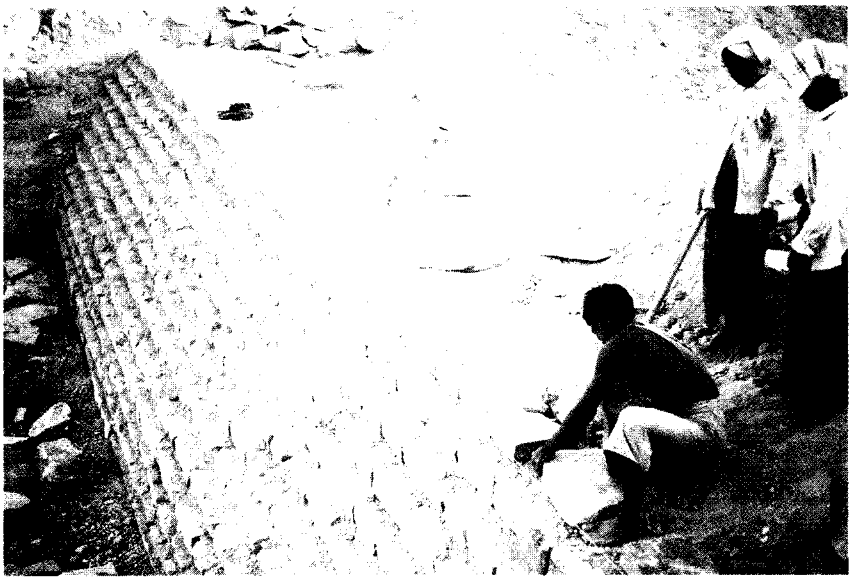
⇨ Proceed with construction of the **foundation of the downstream wall (riser or retention wall) in front of the structure. A second stone wall or rip-rap is placed on the upstream side of the dam.** The first few lines of stones of the foundation are inclined 10-20% uphill to improve stability of the foundation and thus of the retention wall. The retention wall is inclined based on the base and top width of the dam. Large flat stones should be used for the key foundation, side keys (abutments) and retention walls. The foundation should be at least 3' deep and 3' large, including both side abutments.

⇨ By using a rope placed level across the gully adjust the position of the stones which make up the retention wall. The retention walls are then carefully constructed ladder shaped and soil piled, filled and compacted against them.

⇨ **The filling soil is obtained from the reshaped gully sides and from the materials dug out from the spillway.** Therefore the construction of the spillway may take place contemporaneously to the embankment.

⇨ **Compaction should be carefully undertaken by repeated passes of bullocks over the piled layers of soil,** and possibly by using oxen-pulled compactors made out of metal cylinders (drums, barrels, etc.) filled with stones and heavy soil or manual compactors such as buckets filled with heavy soil and stones, wood beams, etc.

⇨ Except for the general dimensions of the structure, i.e. the improvement of the stone keys, the retention walls construction and the spillways design, **the measure is implemented using traditional knowledge.**



SS dam under construction (observe the accurate positioning of the stones)

SS dam under construction (note the reshaping and creation of a new field where before was only a deep gully)

Spillway design and construction: Spillways have to be constructed at the appropriate side (hard materials) of the gully. If both sides are of hard materials, construct the spillway at the side which is facing the direction of the water flow. In addition to detail technical specifications given below, ready made tables for design of spillways based on a peak runoff discharge of 150 mm are provided in Annex 3 to facilitate technicians field work.

The size of the spillway is determined by the catchment area and runoff estimations. THIS IS THE MOST IMPORTANT ASPECT FOR SS DAM CONSTRUCTION.

Spillways have to be of very good quality, stable and with dimensions sufficient to accommodate the 20 years maximum peak runoff discharge. Therefore, dimensions and designs can not be standardized but should accommodate peak discharge runoff even in case of torrential rainfall events (over 100-150 mm per hour).

Step 1: For a given area, compute **the peak discharge rate** (Qpt) by multiplying the corresponding Qp/second/ha ($m^3/s/ha$) taken from Table 1 by the catchment area (CA) in ha.

$$\mathbf{Qpt = Qp \times CA}$$

Step 2: Compute the required flow cross sectional area (a) of the spillway using the corresponding permissible velocity (v).

Values of v are given in Table 6.

$$\mathbf{a = Qpt/v}$$

Step 3: Decide the **permissible depth (d)** and **side slope (z)** of the spillway and calculate the **base width (b).**

- The permissible depth is ranging from 0.3 meters for small spillways to 0.75 meters for large spillways.
- The side slope (z) should be 1 for a stone rip rap, 2 for stiff clays and 3 for medium textured soils.

$$\mathbf{b = \frac{a - zd^2}{d}}$$

Step 4: Add additional 0.3-0.5 meters of freeboard to permissible depth (d) to get the **total depth (D).**

$$\mathbf{D = d + freeboard}$$

Step 5: Compute the top width (T) of the spillway:

$$\mathbf{T = b + 2Dz}$$

Step 6: Draw the diagram of the spillway describing b, t, T, d, D and z.

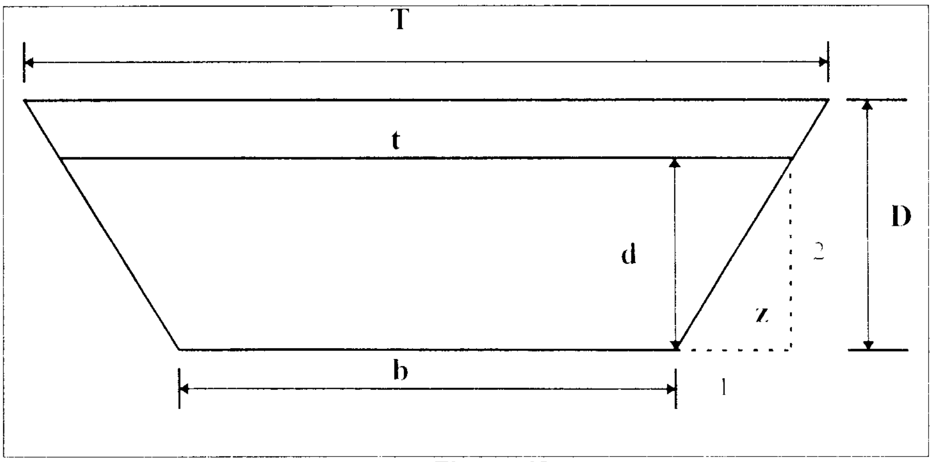


Figure 42

Step 7: Compute the **wetted perimeter P**

$$\mathbf{P = b + 2d\ \sqrt{1 + z^2}}$$

Step 8: Compute the **hydraulic radius R**

$$\mathbf{R = a/P}$$

Step 9: Compute the spillway **bed slope (S)** in meter per meter (m/m) using Manning s formula:

$$S = \left\{ \frac{V \times n}{R^{2/3}} \right\}^2$$

The values of Manning s **roughness coefficient (n)** are given in Table 7.

TEXTURE	VEGETATION	TOPOGRAPHY	RUNOFF COEFFICIENT (K value)	Qp m3/sec/ha
SANDY LOAM	WOODLAND	FLAT (0-5% SLOPE)	0.10	0.0417
		ROLLING(5-10% SLOPE)	0.25	0.1042
		HILLY (10-30% SLOPE)	0.30	0.1250
	PASTURE	FLAT	0.10	0.0417
		ROLLING	0.16	0.0667
		HILLY	0.22	0.0917
	CULTIVATED	FLAT	0.30	0.1250
		ROLLING	0.40	0.1667
		HILLY	0.52	0.2167
CLAY AND SILT LOAM	WOODLAND	FLAT	0.30	0.1250
		ROLLING	0.35	0.1458
		HILLY	0.50	0.2083
	PASTURE	FLAT	0.30	0.1250
		ROLLING	0.36	0.1500
		HILLY	0.42	0.1750
	CULTIVATED	FLAT	0.50	0.2083
		ROLLING	0.60	0.2500
		HILLY	0.72	0.3000
TIGTH CLAY	WOODLAND	FLAT	0.40	0.1667
		ROLLING	0.50	0.2083
		HILLY	0.60	0.2500
	PASTURE	FLAT	0.40	0.1667
		ROLLING	0.55	0.2292
		HILLY	0.60	0.2500
	CULTIVATED	FLAT	0.60	0.2500
		ROLLING	0.70	0.2917
		HILLY	0.82	0.3417

Table 5 ***Peak Runoff Discharge rate/ha (m³/s/ha) based on maximum rainfall intensity of 150 mm/hr (also assume the time of concentration of 30 minutes - see Part 4)***

	v (m/sec.)		
CHANNEL MATERIAL	Bare	Medium Grass cover	Very good grass cover
Very light silty sand	0.30	0.75	1.50
Light loose sand	0.50	0.90	1.50
Coarse sand	0.75	1.25	1.70
Sandy soil	0.75	1.50	2.00
Firm clay loam	1.00	1.70	2.30
Stiff clay or stiff gravelly soil	1.50	1.80	2.50
Coarse gravels	1.50	1.80	-
Shale, hard pan, soft rock, etc.	1.80	2.10	-
Hard cemented conglomerate	2.50	-	-
Small stone rip rap	2.00	-	-
Medium stone rip rap	2.25	-	-
Large stone rip rap	2.50	-	-

Table 6 Values of Maximum Permissible Velocity (v) in m/s

	Roughness Coefficient (n values)		
Type of Channel	**Minimum**	**Normal**	**Maximum**
A. Earth, straight and uniform			
1. Clean, recently completed	0.016	0.018	0.020
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033
B. Earth, winding and sluggish			
1. No vegetation	0.023	0.023	0.030
2. Grass, some weeds	0.025	0.025	0.033
3. Dense weeds	0.030	0.030	0.040
4. Earth bottom and rubble sides	0.028	0.028	0.035
5. Stony bottom and weedy banks	0.025	0.025	0.040
6. Cobble bottom and clean sides	0.030	0.030	0.050
C. Cemented and stone rip rap			
1. Hard cemented conglomerates	0.022	0.025	0.030
2. Stone rip rap	0.025	0.030	0.035

Table 7 Values of Manning's Roughness Coefficient n

NOTE: Refer to Annex 3 tables, developed for field use, which are indicating values of cross sectional area (a) and base width of channel (b) for medium stone riprap spillway based on standard recommended permissible depth (d), sidle slope (z) and total depth (D).

Exercise on spillway design

A spillway is to be designed using the following input values

Catchment soil texture:- Clay
vegetation: - Woodland
topography: - Hilly
area: - 50 ha

Spillway channel materials: - medium stone riprap
side slope z: - 1.0
permissible depth d: - 0.75 m

Step 1: $Qpt = Qp \times CA = 0.2083 \times 50 = 10.415\ m^3/sec.$

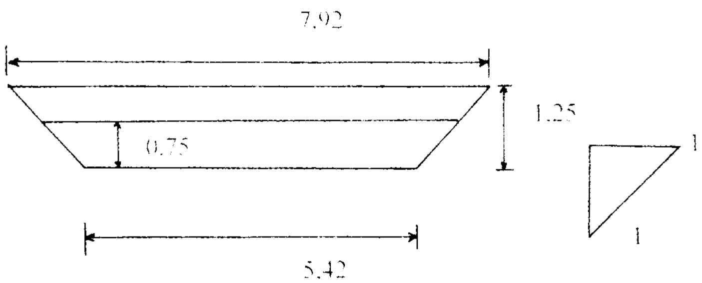
Step 2: $a = Qpt/v = 10.415/2.25 = 4.63\ m^2$

Step 3: $b = \frac{a - zd^2}{d} = \frac{4.63 - 1 \times 0.75^2}{0.75} = 5.42\ m$

Step 4: $D = d + freeboard = 0.75 + 0.5 = 1.25\ m$

Step 5: $T = b + 2Dz = 5.42 + 2 \times 1.25 \times 1 = 7.92\ m$

Step 6: Diagram of the spillway



Step 7: $P = b + 2d\sqrt{(1 + z^2)} = 5.42 + 2 \times 0.75\sqrt{(1 + 1^2)} = 7.54\ m$

Step 8: $R = a/P = 4.63/7.54 = 0.614$

Step 9: $S = \left\{\frac{V \times n}{R^{2/3}}\right\}^2 = \left\{\frac{2.25 \times 0.083}{0.614^{2/3}}\right\}^2 = \left\{\frac{0.00675}{0.7224}\right\}^2 = 0.0087\ m/m\ (0.87\%)$

After construction, **the side of the spillway looking towards the dam should be reinforced with large stones.**

Work norm and Inputs requirements: The work norm is estimated of about 50 cubic feet of volume work per person per day, including transport of stones, reshaping of gully sides, foundation and spillway construction. The volume of work is approximately calculated using the procedures indicated above (page 206). Main inputs required are labour, two or more pair of bullocks for scraping, reshaping, leveling and transport of stones, agriculture tools (crowbars, pick-axes, hoes, sledge hammers, spades, shovels) and temporary sheltering if the site is far from residence. Regarding labour, an average size SS dam would require 6-8 laborers for a period of 2 months and 2-3 pair of bullocks for the same duration.

Integration requirements: The top and downstream sides of the structure should be stabilized with grass and multipurpose trees (see stabilization of physical structures, page 271). Fruit trees are also recommended because of better moisture conditions (raise of water table, etc.) found in the lower part of the dam wall. **Normally, SS dams are part of an entire landcape conservation** effort, which starts from the upper parts of the catchment and proceeds down until reaching the drainage outlets, mostly gullies of various proportions. Accordingly, upper parts of the catchment may be treated with measures for reforestation (for instance trenches, microbasins, etc.), middle slopes with bunds (cultivated fields), small gully tributaries with checkdams and large-medium size gullies with SS dams. It is up to the technicians and farmers judgment to define the extent and type of those measures, **leaving sufficient runoff to reach the SS dam and the newly formed cropped field behind** it. After a few years, when sedimentation is completed, revegetation of the gully sides should take place for both limiting the transport of undesirable coarse materials and salts onto the cropped area and improve the quality of runoff water. The treatment of catchment areas should be a gradual, step by step process.

Management and maintenance: **Check the status of the stone walls and riprap after the first rainy season after the settling and natural compaction of the SS dam structure.** There may be cases where additional reinforcements are required both on the upper and lower side of the embankment.

The **reshaping** of the gully sides normally continues for 1-4 years, depending from the sedimentation rates, the width and depth of the gully, the area of the cropped field expected to be formed and the labour available.

Cropping may take place the first year if sedimentation is high or later. If the soil is suitable for rice cultivation, rice is planted only after 1-2 years to prevent risks of piping (sealing effect). Other crops such as sorghum or sunflower and chickpeas are first planted. In all circumstances double cropping is possible with SS dams.

The spillway should always be checked and eventually upgraded (widened/deepened) based on the first rainy season performance.

Vegetation stabilizing the structure should be maintained dense and vigorous.

Training requirements: Training of farmers in layout and construction is essential. Particular emphasis should be put on the dimensions of the structure, the building of foundations and stone walls (very precise dry masonry work with stones), the continuous compaction of the soil, the correct selection of the spillway emplacement and its construction. Regular supervision by field technicians is recommended (min. once a week).

Limitations:

- Require considerable amount of labour and thus is relatively expensive. However, considering the advantages and benefits it should be considered as an excellent activity for capital investment, use of grants and eventually soft loans in degraded and poverty stricken areas.

- Require adequate technical skills both at technician and farmer level which may not be available.
- Require continuous maintenance and care.

SS dam after construction (see also lateral protection of cultivated fields) in Thoine Kone - Kyaukpadaung

SS dam full of water after rains (the whole area would be planted in the future) in Kuley - Kyaukpadaung

SS dams in series (the ones in the upper part full of sediments and already cropped the first season) in a deep and large gully in Yar Gyi Taw - Kyaukpadaung

Variations to Original Design Technical Specifications

RENOVATION OF EXISTING TRADITIONAL SS DAMS

Definition and scope

Renovation of traditional SS dam is an activity similar to SS dam construction but aimed at **rehabilitating and improving existing valuable traditional SS dams** which have been subjected to various degree of damage by excess runoff (occurring because of heavy deforestation, overgrazing and cultivation of steeper slopes), and thus unable to hold water and sediments for proper cropping. The damage occurred because of embankments were constructed too small or not strong enough to resist water pressure and because of spillways not properly designed and/or constructed which could not accommodate excess runoff during intense showers.

Damage to traditional SS dams occurs in series and besides affecting cropping it may severely affect the water regimes, and induce salinity and sodicity problems.

This activity permit to **preserve lifetime investments and sustain a traditional activity within the current set of environmental conditions and constraints.** Other benefits are identical to those explained for SS dams.

Technical specifications

Type of damage: In most cases, the reason for damage to these structures is a combination of both poor construction standards of the embankment and wrong design of spillways. As a result, breakage occurs either in:

(i) the middle of the embankment, with dam walls collapsing and sliding, fields behind the dam becoming severely eroded (piping, gullying, etc.) and unable to hold water and sediments for proper cropping.

(ii) at the spillway level, with deepening, gullying and side sliding of the spillway and adjacent parts of the dam embankment. Thus fields are also eroded backwards as above and do not hold water and sediments.

(iii) at both the spillway level and one or more parts of the embankment.

Type of activities and phases: Renovation of SS dams occurs in series along drainage lines, starting from the top of the catchment. **Renovation of SS dams focus on both strengthening the embankment, fixing breakage with retention walls, placing stone keys and filling gaps with good soil, enlarging and deepening spillways, provision of aprons and riprap, etc.** For small structures, spillways take the form of large stone checkdams. For breakage of the embankment reshape both sides and bottom of the breach. Then construct a retention stone wall following the same criteria applied for SS dams. Fill the gaps behind the dam with good burrow soil from the side of the gully or the spillway which is going to be improved. Level the field with the help of bullocks.

Spillways are either widened or deepened to accommodate runoff. The spillway design is the same as for SS dam construction. Riprap, drop structures and aprons where spillways have been eroded would be often necessary. In small gullies and light damage, apply checkdams of various sizes to consolidate or improve spillways.

Inputs requirements: same as for SS dams. However, the renovation of existing SS dams is cheaper, i.e. around 40-60 person days average per renovation based upon extent of damage.

Other criteria: same as for SS dams

Traditional SS after renovation (right side of the stone wall), raising of the embankment and improvement of spillway in Thoine Kone - Kyaukpadaung.

SEDIMENT STORAGE AND OVERFLOW SOIL BUNDS (SS BUNDS)

Definition and scope

They are **large and strongly built soil dams or embankments, constructed across gullies, often in series.** As for SS dams, their purpose is to create a new fertile cultivated field by allowing and helping the sedimentation (filling) of the space behind each dam. After the rains, the new fields fill up with sediments and retain enough water to grow crops. The excess runoff move down to the next structure through a spillway. Other purposes are identical to SS dams.

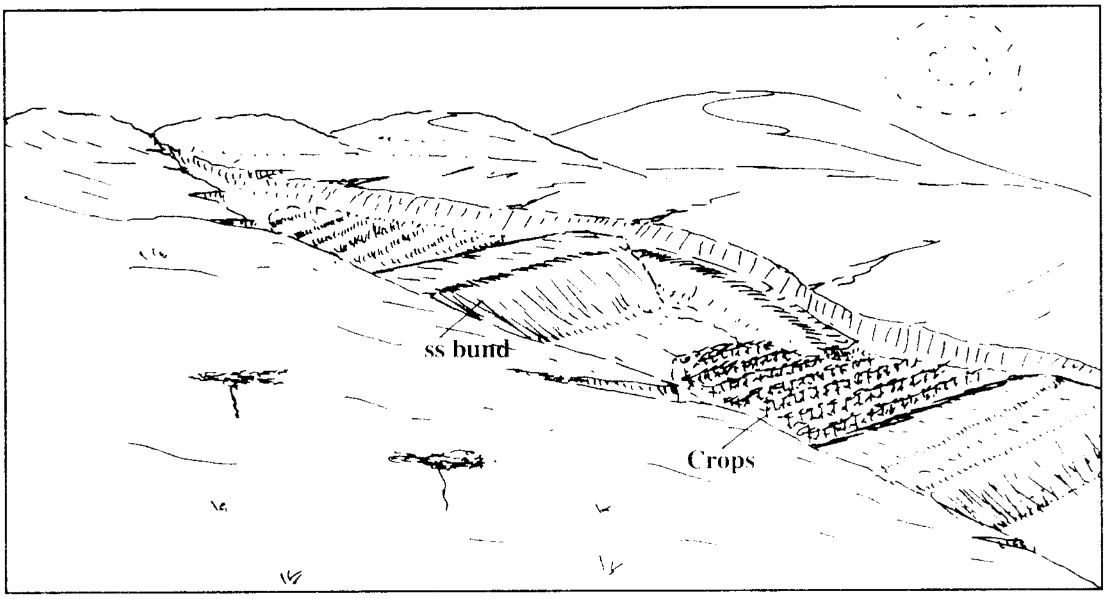


Figure 42 SS bund in a gully

Technical specifications

Site selection: Along medium-small gullies and natural depressions that you wish to convert into productive fields.

The catchment area should be less than 20 acres and at least one side of the gully should be of hard materials such as sandstone, rocks, limestone, etc., in order to construct a proper spillway. If there is no hard rock, the spillway should be enlarged and stabilized with grasses.

The SS bund site should allow the maximum formation of a cropped field area at a minimum cost, and thus decide carefully where is best to close the gully.

Burrow soil should be found close to the site and must be of good quality (not very sandy or very heavy and not saline/sodic).

The criteria for site selection and layout are identical to SS dams, with the exception of the limitation of the catchment area, which should be less than 20 acres otherwise the embankment made out of soil would be exposed to excessive pressure and risks of breakage.

If SS bunds are constructed in series start from the top of the gully.

Finally the size and dimension of the embankment should be estimated as given:

Estimate the size and dimensions of the embankment:

Follow the criteria below to estimate the size of your structure:

- Height of bund (H) should not be more than 7 feet,
- Base width (BW) should be at least double of the height (H),
- Top width (TW) should be minimum 6 feet,
- Top length (TL) and Bottom length (BL) are according to the size of the gully
- Calculate the earth volume work as follows:

(1) V1 = Volume of embankment (cubic feet) = $\frac{H \times (TW+BW) \times (TL+BL)}{4}$

(2) V2 = Volume of spillway earth work (cubic feet) = Length of spillway x base width of the spillway x total depth of channel

V1 + V2 = Total volume of earth work (including foundation and scraping)

Construction phases:

- The SS bund construction starts by ploughing the area where to place the bund and removing of all grasses, branches, roots and decaying leaves.
- Ploughing and moving and piling of soil from the burrow area to the bund area with bullocks until it reaches the required size.
- Compaction should be carefully done, possibly with oxen-pulled compactors made out of metal cylinders (drums, barrels, etc.) filled with stones and heavy soil.
- Start digging the spillway at the appropriate side (hard materials). If both sides are of hard materials, construct the spillway at the side which is at the direction of the water flow.
- If both sides are not of hard material the spillway should be reinforced with a stone riprap.
- **If stones are not available protect the spillway sides with branches and plant hard straws (rice, wheat) in rows across the base of the spillway at 0.5-1' intervals** (see figure 44).
- The length of the spillway should be longer that the width of the bund and have a very gentle slope (0.5% max.).
- Protect the spillway with stone or brushwood scour checks.
- **The size of the spillway should be according to the size of the catchment.** For catchments above 20 acres, design indicated for SS dams are compulsory and stones must be available or transported to the site. Otherwise use the table below.
- Both sides of the soil embankment should be reinforced using brushwood ripraps similar to brushwood checkdams across gullies. The brushwood ripraps should cover the entire width of the structure and extend 3-5' onto the gully sides. Revegetation of the embankment is also recommended with fast covering and vigorous grass/shrubs.
- The size of the spillway can be reduced if the upper part of the catchment is properly treated.

Work norm: For bund construction estimate a work norm of 100 cubic feet per pair of bullocks per day (this includes ploughing, earth moving and compaction). For spillway construction estimate a work norm of 50 cubic feet of volume work per person per day (this includes digging, transporting and filling top of bund). For constructing riprap wall (if necessary and possible) of spillway estimate a work norm of 25 cubic feet of stone per person per day (this includes stone transporting and arranging of stones).

Input requirements: manual labour, bullocks (less in number) and tools similar to SS dams.

Management, maintenance and other criteria: similar to SS dams. However, it is of paramount importance to:

- To strongly compact the bund and stabilize the embankment with trees/grasses.
- To maintain the bund and spillway in case of light damages due to intense showers.
- To deepen the spillway if necessary (peak flow unexpectedly high).
- Treat the upper parts of the catchment with other conservation structures (trenches, bunds, etc.) if necessary.

CATCHMENT AREA (ACRES)	BASE WIDTH (FEET)	DEPTH OF FLOW (FEET)	TOTAL DEPTH (FEET)
1.0	1.3	0.5	2.0
2.0	2.6	0.5	2.0
3.0	3.9	0.5	2.0
5.0	6.4	0.5	2.0
7.5	8.0	0.6	2.1
10.0	9.1	0.7	2.2
12.5	10.0	0.8	2.3
15.0	10.1	0.9	2.4
20.0	12.7	1.0	2.5

Table 8 Recommended base width, depth of flow and total depth of a spillway according to the size of catchment.

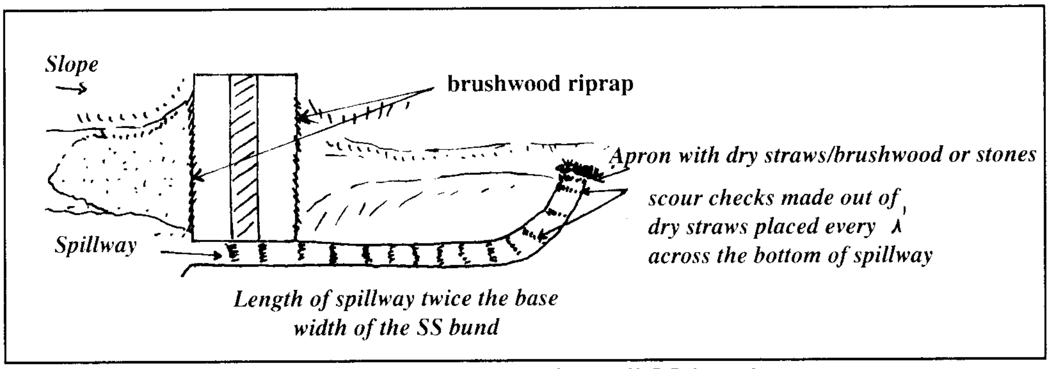


Figure 43 Spillway for soil SS bund

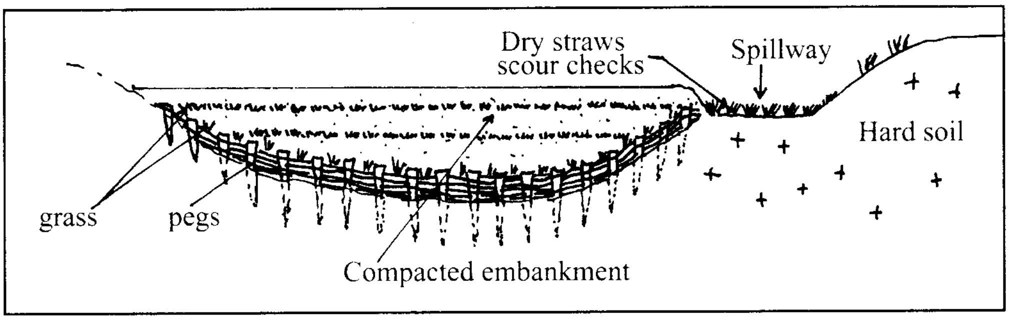


Figure 44 Example of a soil SS bund reinforced with brushwood ripraps

NATURAL RUNOFF WATER SPREADING

Definition and scope

Runoff from a small catchment flows into a cropped area protected by stone faced soil or stone bunds provided with spillways and side overflow devices (wings of decreasing height or side spillways). This is not a measure by itself but rather a method for water harvesting without improved water divertion systems.

Technical specifications

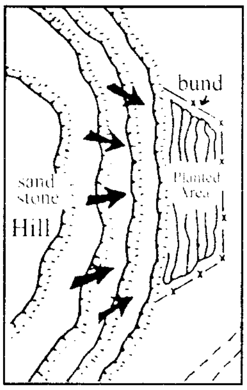
Except for the structures to be used in the cropped area and already explained in the above sections, there are four main situations where simple unimproved runoff farming may be possible:

- alluvial and colluvial deposits at the base of ridges or escarpments;
- alluvial fans where streams leave hilly land and flow over flatter plains;
- stream banks which are intermittently flooded naturally;
- where runoff collects in naturally occurring depressions.

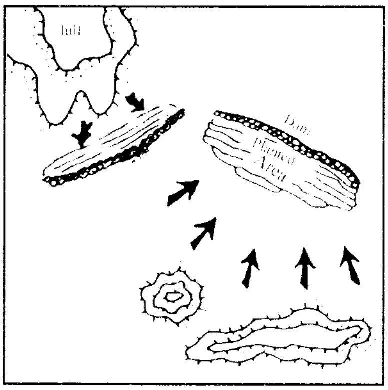
The **catchments should be small** (ratio 3-8:1) and spreading their runoff without concentrating it in one direction only but through several entry points towards the cropped area.

The cultivated area should be protected with one or more **permeable stone barrier and break flows at the entry point of runoff.** The remaining field would be treated with staggered bunds provided with excess water disposal devices. Depending on the size of the field and the nature of the terrain (shallow depressions) large stone reinforced earthen dams with spillway can be placed at the end of the cultivated field. In this case, the measure is similar to an SS dam, except that it is not placed into a gully.

For specifications related to physical structures refer to soil/stone faced and stone bunds, check dams and SS dams based upon the measure(s) selected to collect runoff.



(a) Farming with natural floodwater from a sandstone ridge



(b) Crops grow in fields where floodwater is retained by a low dam

Figure 45 Examples of runoff farming

COLLECTION AND DIVERTION OF RUNOFF INTO CROPPED AREAS BY USING HILLSIDE CONDUITS AND CUTOFF DRAINS

Definition and scope

The difference between the natural floodwater spreading farming described above and here is the artificial manipulation or guidance of runoff, taking place by the means of hillside conduits or cutoff drains. Running water from a catchment is intercepted by a channel and directed, through an entry point, into the cropped area.

Traditional hillside conduits are ancient and widely practiced water harvesting measures in various dry zones of the world (Tunisia, Kenya, Israel, etc.).

Under Myanmar Dry Zone conditions,

- They may be applicable for small cropped areas adjacent to hillsides from which excess runoff could be diverted and thus supplement additional water to the crops.
- Excess runoff from hillsides may be also diverted and concentrated into gullies where series of SS dams are placed, to supplement additional runoff onto the cropped fields, particularly when the catchment/cropped area ratio is not considered sufficient. In this case, particular care should be paid to the cutoff drain outlet into the gully, i.e. riprap of the outlet, drop structures, dissipating energy devices and aprons (see cutoff drain construction).

Technical specifications

Traditional hillside conduits, though effective, are the result of years, if not centuries, of experimentation and adaptation and local skills, and thus do not follow standard technical criteria. It is then difficult to describe them following a systematic model and their applicability should be left to individual interpretation. Therefore these traditional systems are briefly highlighted by the means of figures.

In the following pages improved cutoff drain and water ways construction are described in detail and may be used for water spreading farming following the same principle of the traditional devices shown below.

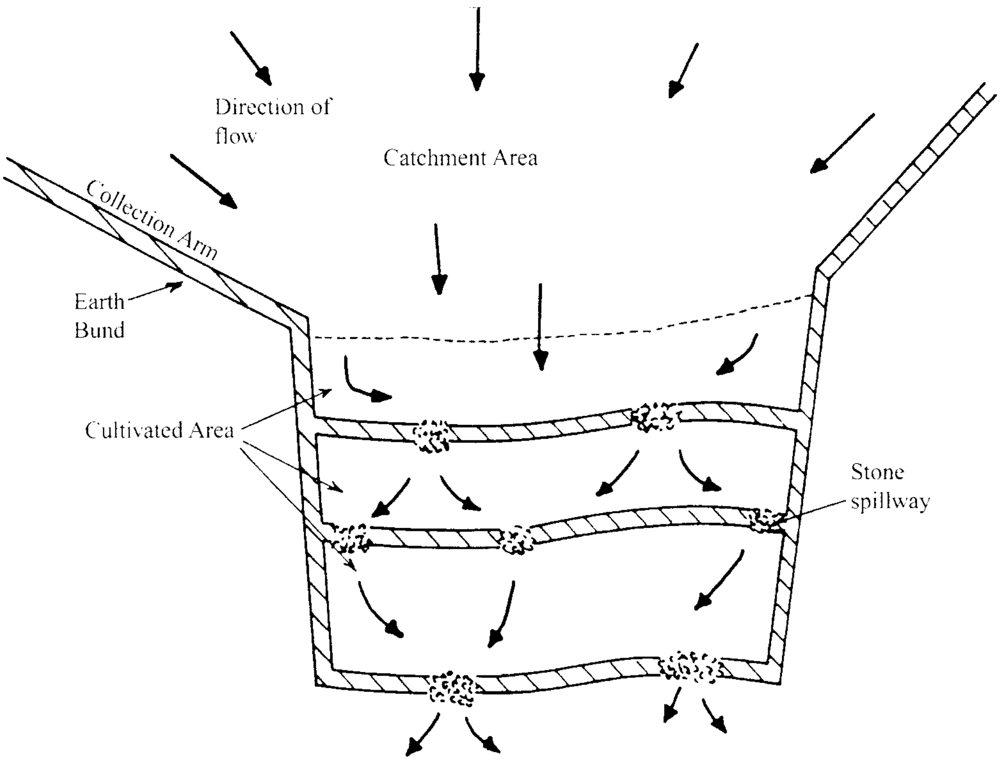


Figure 46 A traditional runoff farming system using hillside conduits in Kenya (Charnock, 1985)

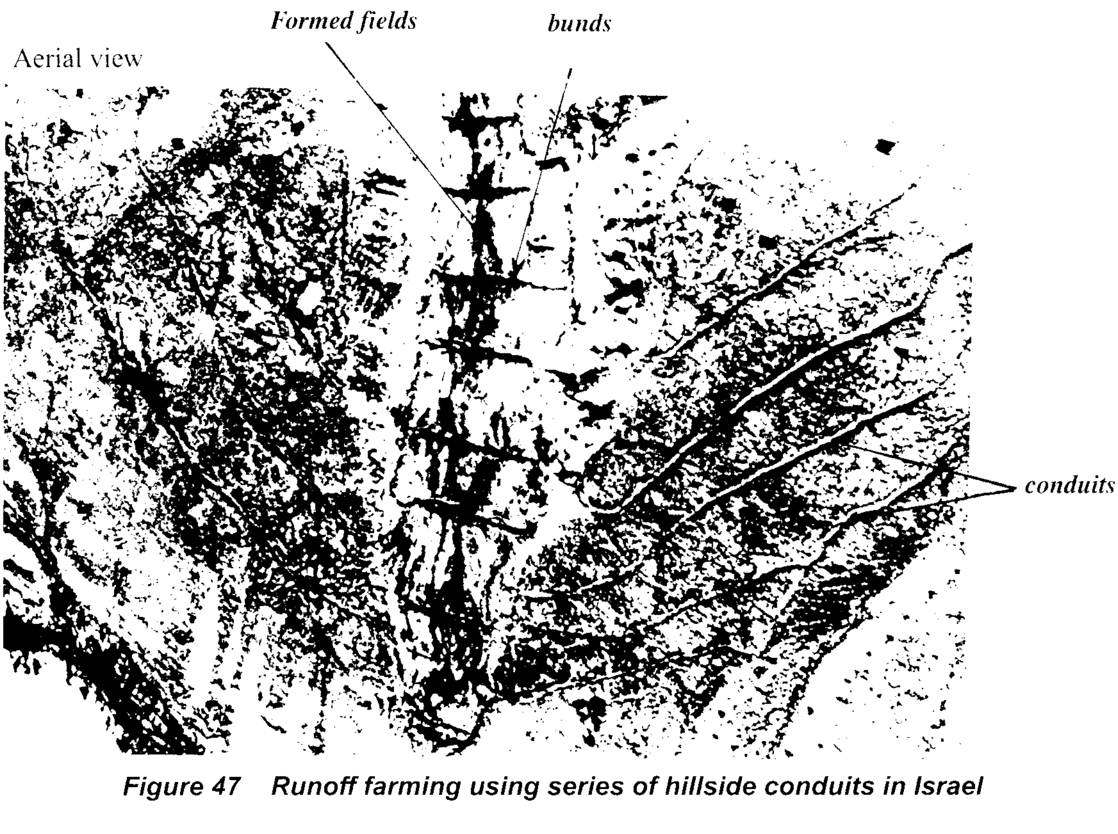


Figure 47 Runoff farming using series of hillside conduits in Israel

CUTOFF DRAIN

Definition and scope

A cutoff drain is a channel used to collect runoff from the land above and to divert it safely to a waterway, river, cultivated field, gully or reservoir. Besides, by diverting excess runoff, a cutoff drain protects the land below from erosion. In the Dry Zone, cutoff drains may be used mainly for the following purposes:

- Protect cultivated land from runoff generated from sparse forest land or degraded grassland, steep slopes, etc..
- Divert additional water to cultivated plots.
- Divert additional water to SS dams cropped areas inside gullies.
- Divert additional water into reservoirs for irrigation and/or domestic uses (including water supply for livestock).

Technical specifications

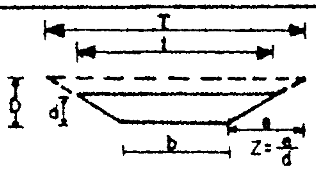
Site selection: a cutoff drain can be constructed in different soils and type of slopes. However, it is preferable to avoid the following situations:

- Very steep slopes (> 50%): it is difficult to dig and size the channel properly. Find below the catchment a break of slope where to construct your cutoff drain.
- Sandy, sodic and heavy expandable clays for the same reasons given for SS dam construction (poor stability).
- Avoid areas with numerous hard rock outcrops areas (difficult to layout , construct and maintain the correct gradient).
- Avoid large catchments (> 50 ha) or make several cutoff drains instead (relay cut of drains).

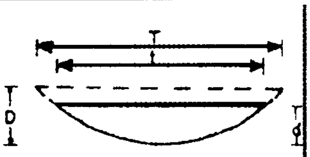
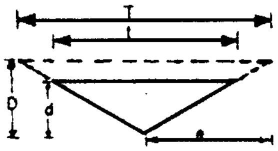
Dimensions: the dimension of the channel follows the same principles and design explained for the spillways (maximum allowable velocity, permissible depth of flow, dimensions of channel, gradients, etc.). However, for practical purposes, the simplified procedures and dimensions are given:

Steps 1 and 2: Same as for SS dams

Step 3: Decide the shape of the channel. A trapezoidal or parabolic cross section is recommended

Cross-Sectional Shape	Cross-sectional area a	Wetted perimeter p	Hydraulic radius $R = \frac{a}{p}$	Top Width t
	$bd + Zd^2$	$b + 2d\sqrt{Z^2 + 1}$	$\frac{bd + Zd^2}{b + 2d\sqrt{Z^2 + 1}}$	$t = b + 2dZ$ $T = b + 2DZ$

Trapezoidal cross section

	$\frac{2}{3}td$	$t + \frac{8d^2}{3t}$	$\frac{t^2}{1.5t^2 + 4d^2}$ or $\frac{2d}{3}$ (approx.)	$t = \frac{a}{0.67d}$ $T = t\left\{\frac{D}{d}\right\}^{\frac{1}{2}}$
Parabolic cross section				
 $Z=\frac{e}{d}$	Zd^2	$2d\sqrt{Z^2 + 1}$	$\frac{Zd}{2\sqrt{Z^2 + 1}}$ or $\frac{d}{2}$ (approx.)	$t=2dZ$ $T= \frac{D}{d}t$
Triangular cross section				

Step 4: Use the following depth of channel (in meters)

Channel slope/gradient		**Maximum allowable velocity (m/sec)**								
Height: Length	(%) Slope	0.3	0.5	0.6	0.9	1.2	1.5	1.8	2.1	2.4
1:100	1	-	-	-	-	-		0.4	0.5	0.6
1:200	0.5	-	-	-	-	-	0.5	0.7	0.9	1.0
1:400	0.25	-	-	0.3	0.4	0.6	0.9	-	-	-

Table 9/a Depth of a channel in meters

Based on the catchment size use the following gradients for cutoff drains:

- catchments 1-10 ha → 0.8-1%
- 10-30 ha → 0.5%
- 30-50 ha → 0.25%

The length of cutoff drains should not exceed 200-400 meters maximum to avoid layout mistakes and possible breakage.

Step 5: Find the channel discharge using the table below. These values are determined by the use of the channel gradients expressed in % and by the depth of the channel given in meters.

For instance a channel depth of 0.5 m and a gradient of 0.5% would have a discharge of 0.95 m^3/sec.

Depth of channel	Gradient (%)		
	0.8-1%	0.5%	0.25%
0.3	0.6	0.4	0.25
0.4	0.9	0.65	0.45
0.5	1.3	0.95	0.65
0.6	1.8	1.3	0.95
0.7	2.25	1.7	1.2
0.8	2.8	2.15	1.5
0.9	3.4	2.65	1.8

Table 9/b Discharge in m^3/sec/per meter width

Step 6: Find the top width of the channel. The width of the channel can be roughly estimated for both trapezoidal and parabolic sections by dividing the estimated runoff from the catchment in m^3/sec by the value of the discharged obtained above. For rectangular sections reduce the calculated width by 1/3.

Example: Find the size of a channel (cutoff drain) to be constructed at the foot of an hilly grassland, with medium cover, and with a general slope of 20%. Soils of the catchment are clay. The runoff area is of 6 ha.

Step 1: Find the summarized characteristics - Cook s method (see Part III, page 56)

the vegetation is grass land (medium cover)	= 15
clay soils	= 40
topography	= 15
Summarized characterstics	= 70

Step 2: Find the corresponding runoff (use table in Part III, page 57). For a value of 6 ha and summarized characteristics of 70, the runoff is 1.6 m^3/sec.

Step 3: Find the maximum allowable velocity using the table 6 given for spillway construction (page 212). In this case, under clay soil and medium cover = 1.8 m/sec.

Step 4: Determine the % and depth of the channel. For a catchment of 6 ha, a 1% drain is selected. For determining the channel depth use table 9/a values. With max. velocity of 1.8 and using a gradient of 1% the depth is 0.4 m.

Step 5: Find the discharge. The reading of the discharge is made by using table 9/b values. For gradient 1%, and depth 0.4 m, the discharge is 0.9 m^3/sec.

Step 6: Find the top width of the cutoff drain.

- For trapezoidal and parabolic sections: Runoff from the catchment area/Discharge. = 1.6/0.9 = 1.8 m
- If the channel is to have a rectangular section = 1.8 -1/3x1.8 = 1.2 m

IMPORTANT NOTE: Because of the lack of sufficient experimentation on the above techniques and the aggressive/erosive nature of rainfall in the Dry Zone, it is recommended to increase the above values for the size of the channel by 10-20% for safety purposes.

Layout and Construction phases: After determining the channel capacity and the dimensions of the cutoff drain the following procedures are to be followed:

- For the layout of graded structures refer to Annex 2 at the end of this guideline.
- While making your graded contour, pegs are put at an interval of 10 meters. These pegs are used as the center of the channel to be excavated.
- Then take additional 4 pegs and a string. The O indicate the central peg and the other four (MNPQ) are placed on both sides based upon the dimensions of the top width of the channel.

  M N O P Q

  |______|______|______|______|

- The distance between NO and OP is equal and it gives the bottom width of the channel. The distance between MN and PQ could be equal if the same side slope (z) is chosen for both. However, in steep slopes the z is often smaller.
- Construction starts digging out NRSP first and then shaping the canal by digging MNR and PQS. The excavated soil is thrown downhill and form a well compacted embankment. It is suggested to leave a space between the ditch and the berm of 15-20 cm to avoid the moving back of the soil into the channel.
- After completion of the work, the gradient of the drain should be checked again and possible errors adjusted.

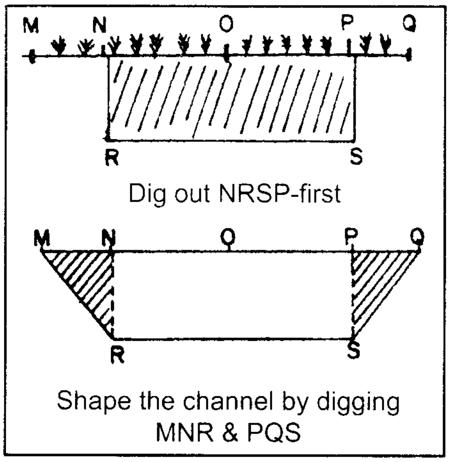
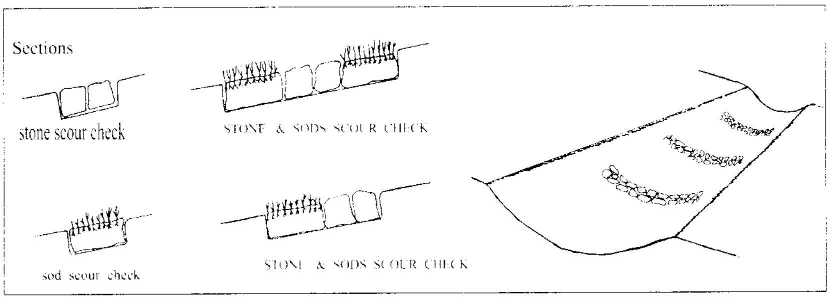


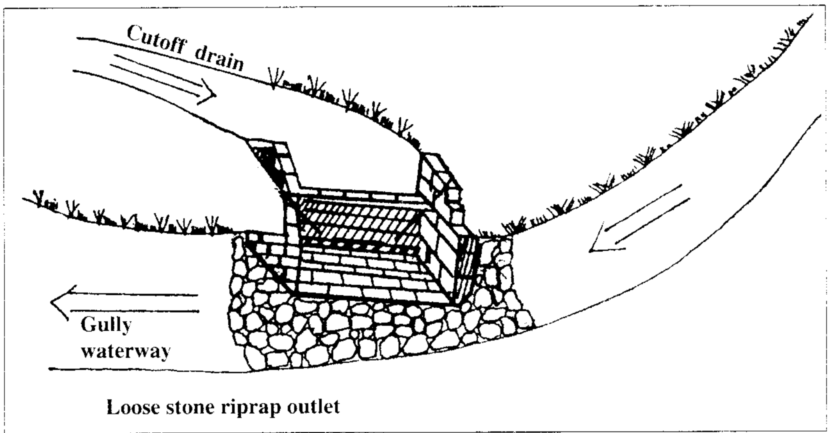
Figure 48 Steps in Cutoff drain construction

Care should be taken to properly reinforce the outlet of a cutoff drain into a waterway, particularly if the cutoff drain diverts water to cultivated fields and to SS dam inside gullies. Otherwise erosion problems are likely to occur. To avoid such problems, stabilize the channel outlet with riprap and drop structures, vegetation, scour-checks and stone pavement as below:

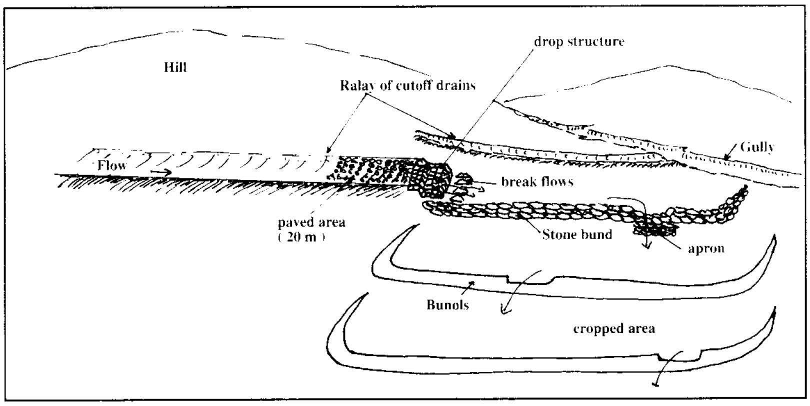
- stone scour-checks are placed at least 20 meters before the outlet, at intervals of 2-3 meters to slow down runoff velocity. Grasses can be planted together with the scour-checks.
- paving with stones (vertical placement) the last 5-10 meters of the cutoff drain is also recommended since stones stabilize runoff flow, avoid erosion and naturally link up with the drop structure and the apron.
- Sodding with grasses is difficult under dry zone conditions.

Integration requirements: The cutoff drain should have its embankment stabilized with grasses and other shrubs. The measure itself is often integrated with one or more soil and water conservation activities (bunds, SS dams, etc.) as mentioned above.





(b) Stone paving + drop structure + apron + check dam for outlets into gullies



(c) Stone paving + drop structure + apron + stone barriers for outlets into cultivated areas

Figure 49 Different outlet stabilization

Work norm and inputs requirements: Around 400 person per km of cutoff drain is a rough average required. However, work norm should be based on volume of earth work. Together with layout, stabilization, and outlet improvement, a 50-75 feet/person/day is tentatively suggested. Inputs are labor and agricultural tools similar for other physical structures (main limitation).

Management and Maintenance: Regular maintenance of the channel, i.e. removal of sediments and obstacles. Check the conditions of the outlet regularly.

Training requirements: The layout of graded structures should be made together with a trained field technician and carried out with great accuracy. Training in outlet improvement and drop structure construction is also required.

WATERWAY

Definition and scope

A waterway is a **natural or artificial drainage channel along the steepest slope or in the valley used to accommodate runoff.** They receive runoff from cutoff drains or graded terraces and carry it away to rivers or gullies safely without creating erosion.

Technical specifications

Waterways can be implemented in various kind of **slopes but < 10%**. For higher slopes (up to max. 25%) they need drop structures at every 10-20 meters for slowing runoff.

It is difficult to construct waterways in either sandy and sodic soils for the same reasons of stability mentioned earlier. In clay soils **paved waterways** can be constructed.

Waterways should be as narrow as possible, particularly where crossing cultivated fields, evacuating excess water from graded terraces or bunds. When evacuating water from cutoff drains, the drainage area should not be bigger than 10-15 ha because a wider area would imply a wider waterway and high costs. A series of small waterways and cutoff drains are preferable than single and large structures.

Waterways are either grassed or paved with stones. Under dry zone conditions, **paved waterways or a combination of the two are preferred.**

Usually, a parabolic shaped waterway is being used and recommended because it nearly approaches the shape of a natural waterway.

Layout of waterways takes place based on the position chosen to receive and evacuate excess runoff from a cutoff drain or graded terrace/bund. Therefore, waterway site selection and construction is integrated with the other measures. Layout normally follows field boundaries and shallow depressions where water tends to drain into naturally. Minimum interference with cropped areas should take place.

Dimensions and construction phases: (see cutoff drain for main channel characteristics).

Step 1: determine the drainage area.
Step 2: with drainage area known, the quantity of runoff should be estimated.
Step 3: waterways are usually designed to accommodate peak runoff discharges expected once every 20 years.
Step 4: determine the gradient(s) of the waterway and the permissible velocity.

Most of the criteria set for the design of cutoff drains are also valid here. However, the waterways are often placed in steeper slopes and thus should be stabilized (stones/grass) and often provided with drop structures or checks (checkdams) at regular intervals.

The following tables give **a simple and rough relationship between the runoff area and the width of a waterway (Table 10) and the width of the waterway and its depth (Table 11).**

Runoff Area serving the waterway	Width of the waterway (m)		
	Slope (0-5%)	Slope (6-12%)	Slope (13-25%)
1	1.5	1.5	1.5
2	1.5	2	2.5
5	2	3	4.5
10	3	6	9
15	3.5	8	12
20	4.5	12	18

Table 10 Relationship between drainage area and width

Width in metres	Depth in metres
0-3	0.3
4-6	0.4
more than 6	0.5

Tabel 11 Relationship between depth(m) of waterway and width(m)

The construction starts by digging the ground. The soil is piled on both sides if the side ground is level or on one side if it is gently sloping.

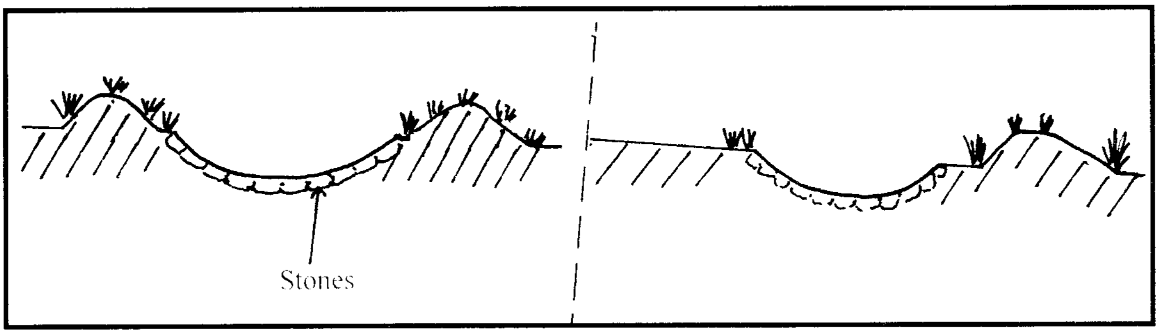


Figure 50 Waterways with level or sloping sides

In the Dry Zone only stone riprap waterways are recommended. The whole bottom width and side walls are reinforced with stones. Some space in between stones is to be left for grass to grow and thus further stabilize the waterway. Drop structures are placed at regular intervals based upon the slope, the narrower the interval the better. The design and construction of the waterway outlet to rivers or streams follow the same recommendations made for cutoff drains.

Work norm and inputs requirements: Around 800 person per km of waterway is a rough average required. However, work norms should be based on volume of earth work. Together with layout, paving, and outlet improvement, a 50 $feet^3$/person/day is tentatively suggested. Inputs are labor and agricultural tools similar for other physical structures.

Management and Maintenance: regular maintenance of the channel, i.e. removal of sediments and obstacles. Check the conditions of the outlet regularly.

Training requirements: The layout of graded structures should be made together with a trained field technician and carried out with great accuracy. Training in outlet improvement and drop structure construction is also required.

Main limitations are the crossing of farm boundaries (tenure) and difficulties to find appropriate outlets. Others are labour, availability of stones, etc.

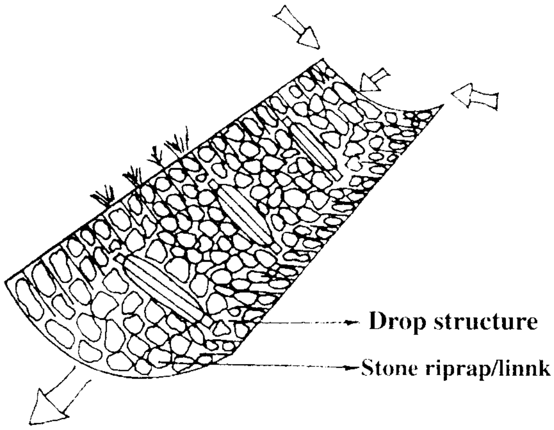


Figure 51 Stone riprap waterway

Example of a stone riprap waterway - (Ethiopia)

AGRONOMIC CONSERVATION MEASURES

STRIP CROPPING

Definition and scope

Strip cropping is a cropping practice where strips of two or more crops are alternately established on the contour or, it is a system of establishing more than one crop in alternate strips following a certain pattern for the purpose of erosion control, crop diversification, and decrease incidence of drought on one crop only (lower risks).

This cropping system is designed as a defence mechanism against soil erosion in areas where the cropping system is dominated by row/sparsely growing crops that often exposes the ground to erosive forces. For instance, row crops like sorghum and maize are susceptible to erosion and need to be grown alternately with soil conserving crops.

Technical specifications

- Crops are sown in strips, one strip being a soil depleting crop and the following a soil conserving/fertility restoring crop.
- If the main crop is maize or sorghum, the second crop can be a legume (e.g. Green Gram, Chick Pea, etc.) that forms good ground cover; in this case maize is regarded as soil depleting/degrading crop while the legume is the soil conserving crop. Erosion is largely limited to the row-crop of cereals and the soil removed from those strips is trapped in the next strip downslope planted with the legume-row soil conserving crop.
- This technique is suitable for second monsoon planting season since the range of crops is wider.
- This measure is effective against soil erosion on slopes < 5% (if well designed) and is best suited to well drained soils.
- The strips can be rotated to optimize the benefits of crop rotations.

Design and establishment: strip width vary with the degree of erosion hazard but are generally between 5, 15 and 45 m with narrower strips on steep slopes and wider strips on gentle slopes. Planting technique is traditional except that it is along the contour. To increase their effectiveness, the density of the legume crop should be higher than normal cultivation. However, on steeper slopes it may be necessary to **add grass buffer strips** of 2 to 4 m wide, placed at 10 to 20 m interval. The width of permanent buffer strips, however, should be negotiated with farmers and determined based upon not only technical considerations but also according to their land holdings (space, tenure issue).

Integration: with bunds, grass strips or any other conservation measure able to reduce runoff and increase storage is recommended. Inoculation of legume crops planted in alternate strips would be also beneficial.

Inputs, management and training: Farmers inputs are sufficient. Improved fast covering varieties can be tried. Inoculum is cheap and available in Myanmar.

Limitations: (a) Farmers may be reluctant to leave space for crops of lower monetary value. (b)The residues from legumes may not be used for mulching or compost. c) Pest control may be a problem.

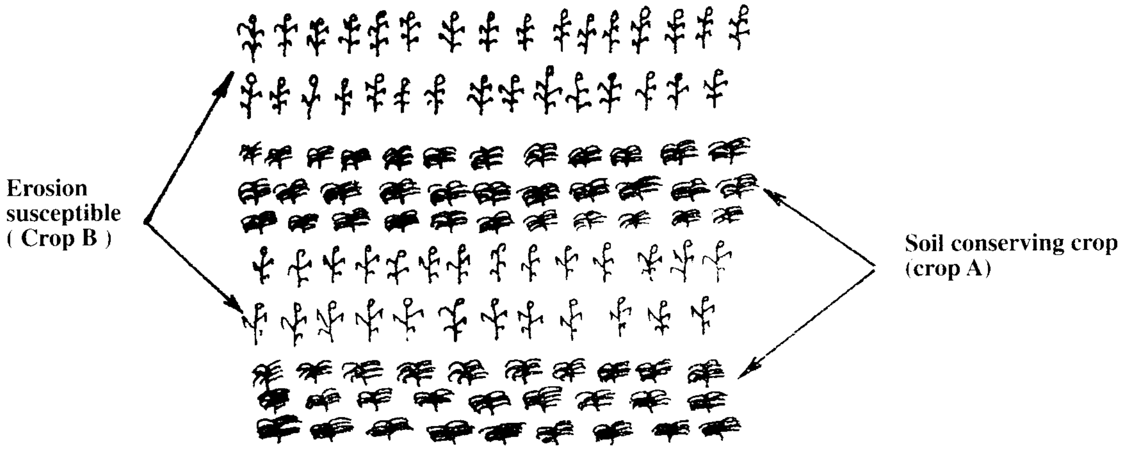


Figure 52 Alternate strips of soil conserving (A) and erosion susceptible crop (B) in a strip cropping practice

LEY CROPPING

Definition and scope

Ley cropping is a cropping system in which legume based pastures are rotated with purely grown crops. Legume based pastures are grown on fallow lands for sometime to improve fertility of the soil and thus the yields of subsequent crops (mainly cereals).

This system has been developed in Southern Australia where its value to agriculture has been enormous. The practice is believed to be feasible under Dry Zone conditions where fallow is a common practice to restore fertility of shallow and depleted soils.

The establishment of dense, productive forage crops during the fallow period (1-few years) provides a thick ground cover, supply forage of good quality after the rainy season, prevent soil erosion, restore soil fertility quicker than bare (and overgrazed) fallow, increase the water holding capacity of the soil and have a beneficial effect on future crop yields. The substantial biomass produced is either harvested and fed to livestock during the dry season or maintained on the ground and incorporated into the soil to raise fertility levels (stubble mulching) before crops return.

Technical specifications

A pasture legume is sown after ripping and a shallow ploughing of the bare fallow. Normally, fertilization is not necessary but 0.5-1.0 Qls./ha of Triphosphate fertilizer application would help the legume seeds to establish and develop their rooting system.

In the Dry Zone, the following legume crops are recommended:

- Siratro (Macroptilium atropurpureum and uncinatum),
- Lablab purpureous (Lablab),
- Stylosanthes hamata (Varano Sylo), etc.

These legumes would be appropriate conserving pasture crops able to restore fertility and provide feed of good quality. They can be planted in mix stands or rows with grass such as Rhodes, Buffle, Panicum (Green panic), or improved native grass, etc. Row planting also reduces competition within and between the species. **In case of mixed pasture, two-third legume seed is mixed with one-third of grass.** Mixing grasses with legumes has the advantage of combining carbohydrates (energy) with proteins (nitrogen fixation of legumes), making a balanced livestock feed.

Results from research shows that Lablab and some clovers are capable of leaving 30 to 60 kg N/ha in the top 20 cm of the soil profile through their root system only. If the aerial part is not removed and incorporated into the soil, this content increases considerably (80-100 kg N/ha). These amounts will not give maximum cereal yields, but they are sufficient to meet the N requirements of cereal crops grown in a subsistence system, for instance for crops such as sorghum and millet. Yields of these two crops were reported to have increase by 30 to 100% based upon soils and rainfall conditions.

The introduction of ley pastures into fallow lands can be either with annuals or perennials species, depending on the length of the fallow period.

This measure can be integrated with rainfall multiplier systems for crop or grassland improvement, various forms of bunds and other agronomic measures such as stubble mulching before the return of the main crop. A very effective supplementary measure is ripping of fallow land and sowing of mixture of grass/legume along the ripped lines.

Inputs and management: Local or improved seeds are needed; labour for ploughing, sowing, weeding and harvesting (farmers own inputs). Others are cut and carry and control grazing of the area.

Limitations refer to conditions where labour is in shortage, seeds are not available and control grazing is difficult. In most circumstances ley cropping is effective and cheap.

COVER/ GREEN MANURE CROPS

Definition and scope

Cover crops are crops grown for the purpose of ground protection under row plantation crops such as pigeon peas or as a conservation crop on fallow lands during the off-season. Cover crops should provide an adequate and rapid ground cover and thus protect the soil from erosion. Besides the protection of the soil, they can also play an important role in replenishing organic matter and nutrient contents of the soil. Maximum benefits can be obtained if the cover crops are legumes and periodically ploughed in.

Green manure crops are crops grown to maintain or increase the soil organic matter and nitrogen content of the soil. Before reaching their maturity or start competing for moisture with the row crops, their biomass is incorporated into the soil. They also protect the soil against erosion but not as much as cover crops.

Technical specifications

- Suitable cover crops should be easy to establish, cover the ground quickly and should be aggressive enough to exclude weed growth but not too aggressive as to cover its companion crop or compete adversely with it for light, water and nutrients. Several legumes such as Pueraria Phaseoloides, beans, chick peas, grams and siratro may be tried as cover crops whereas several varieties of drought resistant peas (cowpeas, chickpeas, etc.) and beans should be tested as green manuring crops.
- The **biomass** should be incorporated into the soil by a light ploughing, possibly at the end of the first monsoon or in the middle of the second monsoon. Green manuring crops may be planted also in the middle of the second monsoon or on the residual moisture of the late rains and grow during the first few months of the dry season until they can be ploughed in and be of use for the next season crops.
- **Main inputs** required are varieties of seeds suitable for this purpose. The system should be tried in series of demonstration plots designed for different combinations of green manuring or cover crops and row crops, sowing and ploughing times, etc.
- **Integration:** With measures able to increase or maintain water availability such as bunds and rainfall multiplier systems is recommended. Ripping is also suggested.

Inputs and management: Local or improved seeds are needed. Control grazing of the area is required.

Limitations: **The technique may be labour and time consuming and not giving particular good response in terms of yield increments under Dry Zone conditions, specially during the first year. Farmers may be reluctant to use legume produced biomass for manuring purposes instead for animal feed.**

INTERCROPPING

Definition and scope

Intercropping is a practice of growing two or more crops along the contour simultaneously in the same plot in a fixed pattern in one season. The aim of intercropping is to increase crop production and provide protection to the soil against erosive forces. Intercropping is a widely applied traditional technique (with pigeon peas, cotton, etc.).

Different planting times and different length of growth periods **spreads the labour requirement of planting and harvesting, but also allows mid-season change of plan** according to the rain in the early part of the season.

The various leaf arrangements of different plants allow light to be better intercepted over time. The contrasting patterns of root growth, which utilize different soil layers, optimize the use of available soil moisture and nutrients. Mixed stands of crops suffer less from insect damage and diseases, and they normally protect the soil surface more effectively than pure stands.

Overall output per unit area can be greater from intercrops than single crops and chances of total crop losses are lower than in pure stands.

Technical specifications

In the Dry Zone, the practice seems to be more feasible for row crops such as maize and sorghum or, pigeon peas and cotton. These crops do not form a good ground cover at an early stage from establishment. At a later stage, when crops begin to form a denser cover, the canopy is high above the ground level and runoff is free to move in between plants and erode the soil.

At the same time, these crops have bulky biomass which is not often returned to soil. The big stalks are often removed for various purposes. There is very little return to the soil, even from pigeon peas which are legumes. To contrast this nutrient mining system, suitable legume species (chick peas, cowpeas, green gram, soyabeans, forage legumes, etc.) or conserving crops should be planted in the spaces left between rows.

Fodder legumes tend to produce more biomass than food legumes and the amount of nitrogen fixed is proportional to the biomass produced by the crop. The effect of N-fixation is not much felt by the current crop but rather by the crop planted next season and often for more than one year (see Table 12).

	Wheat grain yield (tons/ha)		
Treatment	1978	1979	Mean
Sole Sorghum	3.40	3.6l	3.51
Sorghum + green gram	4.05	3.75	3.19
Sorghum + ground nuts	4.33	4.01	4.17
Sorghum + grain cowpea	4.30	4.03	4.17
Sorghum + fodder cowpea	4.69	4.11	4.40
Sorghum + soybean	3.61	3.47	3.54

Source: Nnadi and Hague (1985)

Table 12 Grain yield of wheat in relation to preceding intercrops.

There should be attention paid to **maximize the benefits from intercropping** depending on the interest of the farmers. In most cases farmers want to minimize the reduction of yield of the main crop. Then, **adjustment to the sowing dates** should be made to minimize competition between the main crop and the legume (companion crop). In this regard, companion crops should be sown 2 to 3 weeks after the main crop. With such planting calendar, the reduction of the main crop is minimal and the total yield from both crops is much higher than the yield of purely grown main crop. Some intercropping would also be advantageous to control incidence of pests because of crop diversity.

Integration with bunds, ripping and rainfall multiplier systems is recommended to increase water availability and thus reduce competition, organic and inorganic fertilization to compensate for some competition.

Input and management requirements: refer to the availability of suitable varieties of companion crops and planting calendars. This technique may require more labour than the one required for crops standing alone (although it may be the opposite since it spreads the labour requirements over different periods). The different combinations should be tried in demonstration plots before wider recommendations can be made.

Limitations refer to the possible competition for water and nutrients between crops and the total produce expected from the area intercropped that may not be economically satisfactory.

-B

RELAY CROPPING

Definition and scope

Relay cropping is a practice of growing two or more crops during the same growing season with a certain overlap between planting of the second and harvesting of the first crop (Fig. 53). This is usually practiced to take advantage of the residual moisture left in the soil and the open space between matured plants. The intention is to leave the soil in better conditions for the next season crops. For instance, before sorghum is harvested some legume crops may be sown in between rows and then grow on the residual moisture. Once some biomass or grain is produced, the crop residues are incorporated into the soil for future use.

Technical specifications

There are two conditions for the implementation and success of the practice. Firstly, the residual moisture should be reliable enough to support growth of the second crop. Secondly, the first crop should be a row crop with adequate space between rows to allow planting of the second crop. In case the first crop is not a row crop or farmers are reluctant to plant it in rows instead of broadcasting, there would be the possibility of planting the second crop immediately after the harvest of the first crop provided that the residual moisture is sufficient. The latter should be seen as sequence cropping instead of relay cropping depending on the synchronization between the harvesting of the first crop and the planting of the second crop. **Sequence cropping is also called double cropping.**

This technique is suitable when **the first crop is planted at an early stage**, benefiting from early rains or a good first monsoon. Then, the second crop would have better chances to grow and produce sufficient biomass. Ripping would significantly improve the moisture intake and its residual amount for the second crop. Legume crops suitable for relay cropping are the ones mentioned above for other biological measures.

Other considerations: similar to the ones above for intercropping and ley cropping.

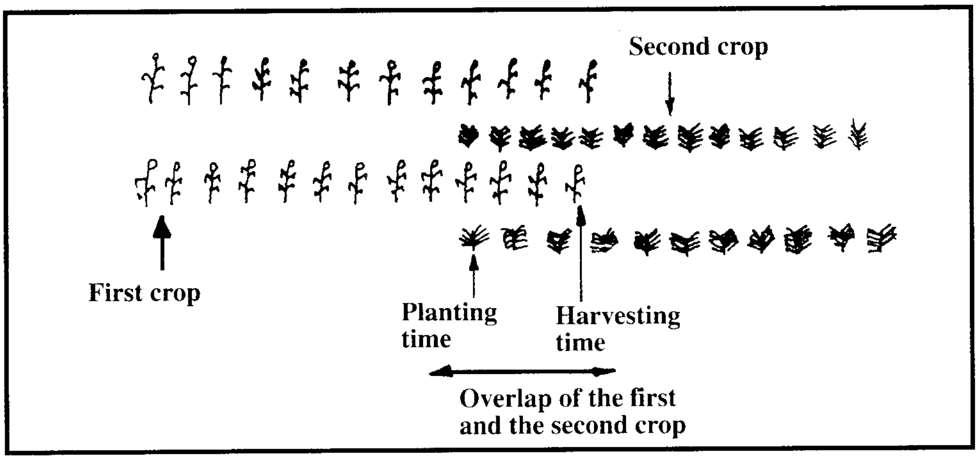


Figure 53 Relay cropping

MULCHING AND CROP RESIDUES MANAGEMENT

Definition and scope

Mulching is the covering of the soil with crop residues such as straws, maize/sorghum stalks or standing stubble. The cover protects the soil from raindrops impact and reduces the velocity of runoff. Maintaining crop residues on the farm or applying mulches has a number of advantages in controlling soil erosion and improving fertility of the soil.

Mulching indeed is one of the most effective methods to minimize erosion. A crop residue covering the ground decreases raindrop erosion, slows down the water flows and increases the infiltration rate as the pores of the soil are not clogged (through surface sealing by clay particles after rains). It also encourages insects and worms to make holes into the ground, thus increasing the permeability of the soil. The effectiveness of mulching for infiltration is illustrated in Figure 54.

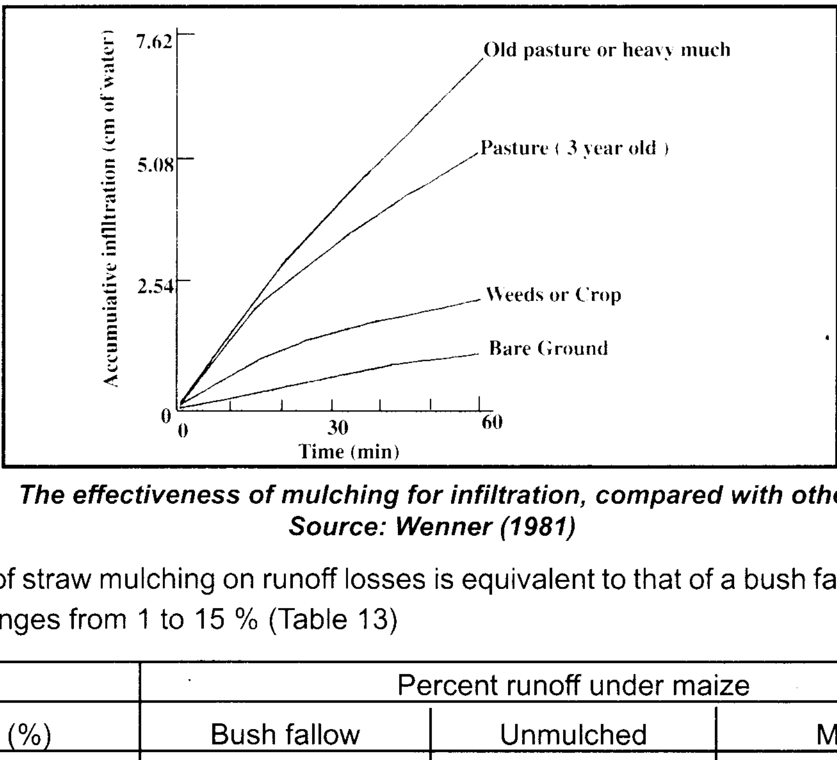


Figure 54 The effectiveness of mulching for infiltration, compared with other practices - Source: Wenner (1981)

The effect of straw mulching on runoff losses is equivalent to that of a bush fallow cover for all slope ranges from 1 to 15 % (Table 13)

	Percent runoff under maize		
Slope (%)	Bush fallow	Unmulched	Mulched
1	1.7	6.4	2
5	1.4	40.3	7.7
10	1.7	42.3	5.7
15	2	67.6	1.9

Table 13 Effect of mulching on runoff losses (Lal , 1970)

The second major advantage of mulching/crop residue maintenance, is its potential for sustaining productivity. Depending on various conditions, any plant material going back to the soil has a potential of increasing/maintaining soil organic matter. Soils with low organic matter content are usually susceptible to erosion, especially when the soil is devoid of vegetation. Such soils when cultivated or subjected to any physical disturbance, suffer physical deterioration. This eventually leads to surface sealing during heavy storms with increased runoff and soil erosion. Physical deterioration of the soil also leads to increased soil compaction and this adversely affects crop production in various ways. Compacted soil layers do not allow percolation of sufficient moisture and aeration, resulting in shortage of moisture and air supply for the crop. The compacted layers are also too hard for the roots to penetrate. Stagnation of root development will dramatically reduce yields, even if other inputs like fertilizers are applied.

Mulching, in addition to its positive effects on soil structure also helps in reducing evaporation and maintaining soil moisture. The improved soil structure also will have an effect on moisture retention and consequently higher water budgets for the growing crop.

Technical specification

- Under the Dry Zone conditions, a number of crop residues can be used. For instance residues from Sesame, various legume crops and other straws or dry grass. Sesame residues can be applied at the surface of the soil (normal mulching) whilst legumes (grams, beans, peas, etc.) are better incorporated (stubble mulching) not to loose valuable nutrients (Nitrogen).

- It is recommended to scatter the residues over the whole surface in a 2-5 cm thick layer. At least 40% cover is recommended to reduce erosion by 60-70% based on slopes and type of soils. In sodic and saline soils, sandy soils and soils with very low level of organic matter surface mulching does not seem to be very effective. In this case stubble mulching is preferred.

- **Integration** naturally occurs with different sort of contour bunds, rainfall multiplier systems and ripping aimed to increase moisture availability, accelerate the breakdown of the organic residues and avoid runoff.

- **Inputs required and management** are labour for mulching and often for the collection of additional residues if existing crop residues are insufficient or partially used for other purposes. Attention should be paid to the possibility that some crop residues may harbour insects or diseases that may be detrimental to the next crop. In this case, crop residues should be removed and used for other purposes. It is better to avoid crop residues hard to decompose (high lignin content) because they may substract N to the next crop and thus reduce the efficiency of fertilizer applications.

- **Limitations** are expected in terms of acceptability of the practice by the farmers. In general, mulching and crop residue management would be difficult under the Dry Zone conditions as these materials are badly needed to supplement the short feed supply during the dry season, or used for jaggery making or sold for extra income. However, demonstrations should take place in small areas until clear evidence on positive effects on conservation and increased productivity can be obtained. For demonstration purposes, incentives may be given to farmers as a compensation for the loss of income due to the utilization of crop residues for mulching.

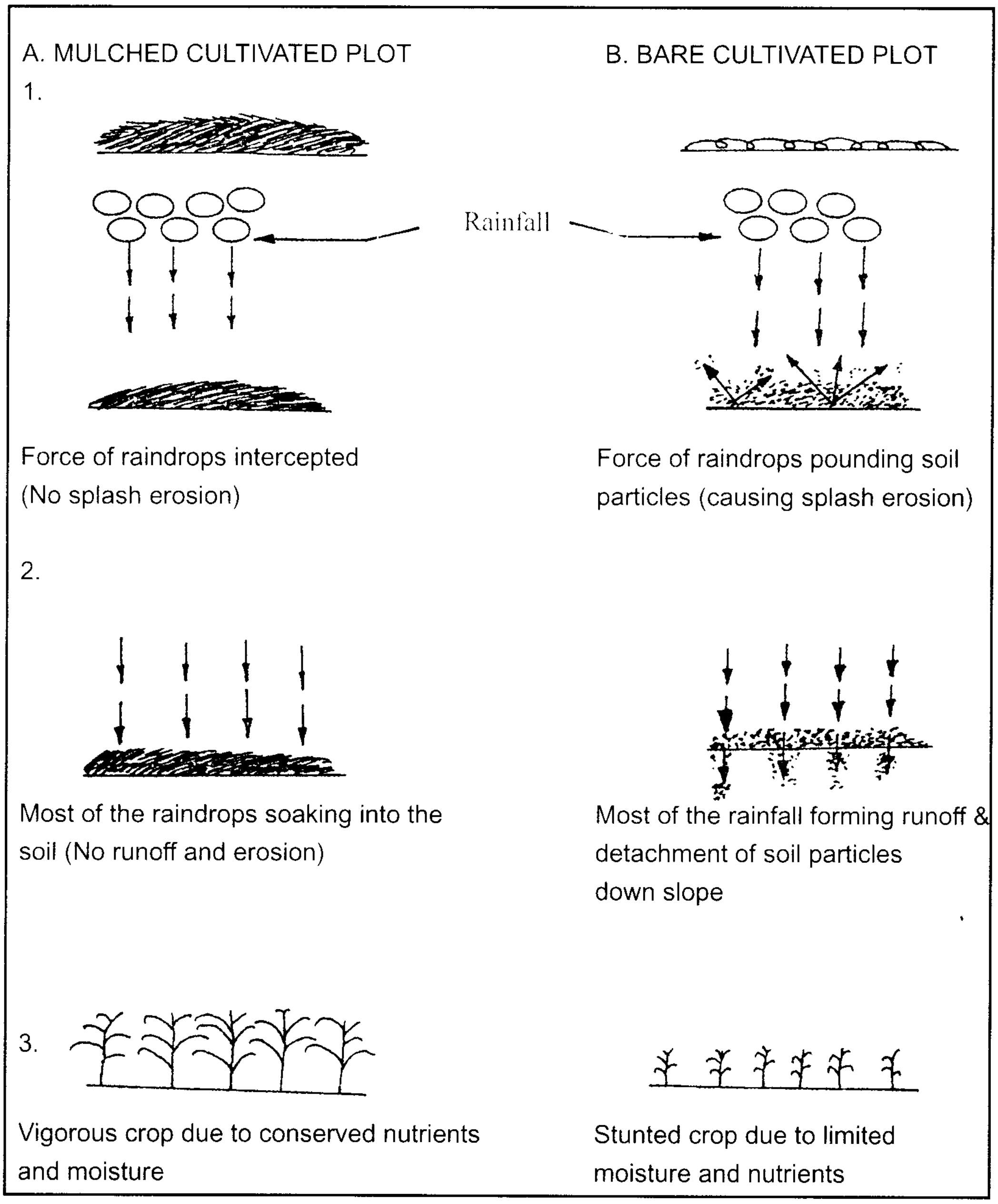


Figure 55 Comparison of the effect of raindrops on mulched and bare cultivated plots

CROP ROTATION

Definition and scope

Crop rotation is one of the oldest practices known to man **for fertility restoration and pest/disease control** and it consists of growing different crops one after another on the same piece of land. Plants of the same crop develop their roots at the same depth of soil profile and thus the proliferation of the root systems in the same depth results in a strong competition for moisture and nutrients. Therefore, if the same crop is grown on the same land year after year, the soil nutrient in that stratum decreases sharply and the crop yield consequently declines. On the other hand, if different crops are rotated, the depletion of soil nutrients and decline of crop yields are not as serious as when the same crop is grown year after year. Different crops have different characteristics that enable them to exploit the soil at different depths.

Crops also differ in terms of their effect to the soil. Some crops restore or build fertility while others deplete fertility. For instance, legumes fix atmospheric nitrogen and hence enrich soil fertility. On the other hand, cereals such as sorghum deplete soil fertility since their big stalks are exported for different uses. Forage legumes and grass provide good ground cover which improve the organic status of the soil, which in turn improves the soil structure through biological activities enhanced from dead roots and leaves of forage plants.

The improvement of plant cover and soil structure through sound crop rotations substantially **influences the effect of runoff and levels of soil loss.** The benefits of crop rotation in soil conservation can be illustrated by the results obtained in Kenya, at 20% slope, with loamy soils and rainfall of about 960 mm/year (Table 14).

Practice	Runoff %	Soil loss ton/ha
Continuous maize	40	242.21
Maize in rotation	24	103.81
Wheat in rotation	25	14.83
First year ley	18	1.48
Second year ley	13	0.49
Permanent pasture	4	0.0049

Source: Wenner (1981)

Table 14 ***The effect of crop rotation with pasture ley (legume and grass) on runoff and soil loss.***

Crop rotation in addition to fertility restoration and soil and water conservation is a **popular traditional practice of controlling diseases, pests and weeds infestation.** It is well known that different crops are not equally susceptible to the same kind of pests or diseases. Growing the same crop year after year will provide an opportunity for pests to multiply and outbreak virulently after two or three years of continuous cultivation, eventually leading to serious loss of crop yield. The same problem holds true for weed infestation.

Technical specifications

The specifications are left to agronomists and farmers who have to decide the best alternance between crops and their effect on soil loss and fertility based upon local conditions.

A rotation is a practice strongly influenced by economic factors. In dry zones, old sound rotations have been shortened or changed to accommodate other crops more beneficial in monetary terms or required for food. This is the result of an increased demand of produce required to satisfy the needs of an ever increasing population, resulting in the vicious cycle of land degradation described in Part I. Technicians are often facing problems to recommend a change in rotation, not because farmers do not like it but because they can not afford the change. It is then suggested that improved rotations should be proposed to the land user together with an entire package of additional measures able to improve yields of the main crops so that the rotation becomes acceptable. For instance physical structures for additional moisture retention, ripping, fertilizer application, manuring, etc. Besides, wherever possible, existing rotations should be improved by avoiding the removal of crop residues, green manuring, mulching and various other techniques described in this section.

In the Dry Zone of Myanmar, the rotation should be seen within a dual perspective, i.e. within the year and between successive years of cropping. Within the year takes into consideration the two cropping seasons derived from the bimodal pattern of rainfall or first and second monsoon cropping seasons.

Taking the three townships assisted by project MYA/99/006, i.e. Kyaukpadaung, Magway and Chaung U as a reference to represent the main type of crop rotations found in the drier part of the Dry Zone, the following general considerations can be made:

First monsoon crops:

- Generally, during the first monsoon Sesame and ground nuts are sown in most parts of the Dry Zone (Sesame prevalent in Chaung U and Kyaukpadaung and ground nuts in Magway). Pigeon peas and, to a lesser extent, short staple cotton are also commonly intecropped or grown in pure stands. There should be a tendency to select drought resistant varieties of grams to replace ground nuts which is notoriously less nitrogen-effective and more degrading than other legume crops. Grams (green or black grams) should be also intercropped with pigeon peas. Economic factors (price, maketing), supply of seeds and reliability of such crops to withstand periods of drought would influence the adoption of this practice.

- In Kyaukpadaung and Chaung U rice is also sown in lowland areas or in traditional terraces (SS dams) which capture run-on water. This allows the extension of the growing season and the possibility to grow rice and a second crop on the residual moisture (sunflower or chick peas). Traditionally, rice is grown largely by transplanting seedlings from nurseries. However, in drought years, due to scarcity of water, seedlings may be affected in several locations and thus jeopardize the possibility of growing rice. Direct seeding with proper varieties should be encouraged. This has several advantages. It shortens the crop life cycle allowing the second crop to grow better; it is less labour intensive and avoids transplant shock. Transplanted rice has no inherent yield advantage over directly-seeded rice in most parts of Asia provided it is sown timely (July). However, these recommendations should be taken with care, particularly in view of the availability of suitable varieties for direct seeding in Myanmar. An interesting supplementary measure meant to increase nitrogen fixation is the algalization of rice fields.

Second monsoon crops:

- Common crops sown at the beginning of the second monsoon are green gram, sorghum (mostly for animal feed), long staple cotton, late sesame and other pulses. Millet is also sown, often mixed with sorghum or along farm boundaries and bunds. Late monsoon crops are sunflowers and chick peas, mostly in the traditional terraces/dams and in some soils which have better moisture retention capacity and fertility. Wheat is also found in Chaung U.

- The improvement of rotations should aim again to encourage the adoption of legumes intercropped with cotton. Grams intercropped with cotton and sunflower at different rates (1:1, 1:5, 1:10) seem promising and should be encouraged, leaving residues of legumes mulching the ground after harvest of seeds. Similarly sorghum and millet should be planted in rows and intecropped with legumes at different ratio. Fields planted with cotton, sorghum, millet and wheat should be planted the second year with a different set of crops (intercropped or in pure stands), to limit pest infestation and decrease the mining of nutrients.

- In the Dry Zone of Myanmar, besides the possibility to introduce improved varieties of legumes and other crops, existing cropping patterns offer already ample scope for improvement in terms of optimizing the sequence of crops, their arrangement and sowing dates. In this respect, accessibility to improved varieties of legumes (locally improved), possibly inoculated with highly efficient strains of rizhobia would significantly improve fertility and yield of crops.

- Another aspect which should be considered in the Dry Zone is the improvement of fallow lands which should be considered as part of the rotation, to the extent of abandoning poorly managed fallows for well managed and integrated crop land systems (see Fallowing, page 251).

CHOICE OF CROPS AND PLANT POPULATION DENSITY

Definition and scope

The choice of crops and their population density should be geared towards crops able to sufficiently and rapidly cover the soil surface and thus protect the soil against soil erosion, and produce satisfactory yields with the limited moisture available.

Technical specifications

Different crops respond differently to moisture stress conditions and cover the soil differently. For instance, early maturing varieties are more adapted to limited moisture regimes than late maturing varieties. Cereals such as maize have basically an adventitious root system that has the potential to extend along the line of least soil resistance, which results in rapid lateral extensions while the surface layers remain moist. On the other hand, broad leaves plants such as soybean have a tap root system and consequently achieve rapid vertical root extension and are better adapted to dry soil conditions compared to cereals such as maize. Other cereals such as sorghum and millet are also drought resistant. **Early maturing varieties are normally more resistant to moisture stresses than late maturing varieties. The best condition is fulfilled when early maturing varieties are varieties that can be planted early.** In this case these crops manage to cover the soil at the time when the most erosive rains occur. Several varieties of Sorghum, Millet, Green gram, peas and forage legumes have been developed in several parts of the world to meet this requirement. Some promising varieties are also developed in Myanmar.

Plant population has a marked effect on the rate of soil moisture loss in crop production. In crop fields, moisture is lost from both soil surface (in the form of evaporation) and from plant leaves (in the form of transpiration) which in all is described as evapotranspiration. In dry zones, the population density should not be too high in order to optimize the use of limited moisture. In a situation of low plant population evaporation from soil surface is high but more water is available to plants and yields are normally higher than in a situation of high crop density, where not all plants may reach maturity or overcome dry spells between showers.

These measures should be integrated with water harvesting systems such as tie-ridging, contour cultivation and other agronomic measures (mulching, etc.) in order to increase the water availability to plants and ensure both good yields and soil protection.

Inputs and limitations are similar to those mentioned for other agronomic practices and refer mainly to the difficulty of introducing changes to the existing cropping system that would imply new and unexpected risks from the farmers point of view. Series of demonstration should be tested first and monitored for a few years.

ROW ARRANGEMENT AND CONFIGURATION

Definition and scope

This technique is linked with the choice of crops, their density and the rotation. Experiences of dry farming in Israel and other countries show **that different row arrangement/ configuration influences to a large extent the water use efficiency of plants and crop yields.** If plants are arranged in an equidistant pattern, interference will be delayed for the longest possible period and maximum early individual growth will be achieved. The configuration may also influence competition between young plants at an early stage of development, so that to limit consumption of precious moisture and keep sufficient water reserves for the reproductive stage.

Technical specifications

A highly successful method of row spacing is used for sorghum in Israel. When the amount of water stored into the soil is known to be less than the requirement, double row spacing is used instead of single row spacing to suppress early vigorous growth of the seedlings.

The **use of double row spacing as compared to single row spacing increases competition among the plants and prevents tillering and limits leaf development and water use at an early stage.** Regardless of its negative effect on the final crop yield, suppression of vigorous development during early growth, markedly reduces the rate of soil moisture depletion during the early stage of development. As a result of the reduced rate of consumption, there would be more moisture reserve for the reproductive stage. It also often coincides with a period of less erratic and more abundant rainfall.

This system has been adopted in marginal areas of Australia. It entails substantial yield sacrifice in good years, but in bad years it protects against total failure. Hence, row arrangement can be used to manipulate competition among plants and the rate of moisture consumption. This would secure a certain level of production under fluctuating climatic conditions.

A traditional method is also the farmer s practices of **thinning** crops sown at the beginning in a dense stand and then reduced to the required number (practiced on Sesame during first monsoon).

Integration with water harvesting techniques would certainly have a positive effect in both the arrangement and configuration of crops. For instance tie-ridging would need specific and careful spacing between rows and plants in order to exploit to its maximum the increased amount of moisture available.

For other specifications refer to the measures described above.

FALLOWING

Definition and scope

Fallowing is perhaps the oldest system of replenishing fertility and moisture levels known to man. Besides fertility restoration, in dry zones fallowing has a particular significance because its scope is also to conserve moisture from the preceding season(s) to meet the water needs of a crop intended to be grown the following season. The amount of water stored by the fallow depends on rainfall during the fallow period, the length of the fallow, infiltration capacity of the soil, waterholding capacity of the soil and the rate of moisture loss from the soil.

However, in the Dry Zone one or two (or more) years poorly managed fallows are too short to build up significant soil organic matter and store moisture. In fact, most fallows are characterized by significant bare ground, a mixture of weeds that seed uncontrollably, heavy treading, overgrazing, removal of nutrients by erosion and crusting problems. These fallow lands do not increase the sustainability of the system and their cultivation is delayed for years and only during a season of abundant rainfall.

In this respect, the improvement of fallow lands is intended in two ways:

- Proper management of fallow lands through legume leys (ley cropping), to increase soil nitrogen, organic matter and improve soil structure. The system also provides high-quality stock feed.
- Convert poorly managed fallow lands into well managed crop lands through an entire set of SWC measures (physical and biological).

Technical specifications

Improved fallow:

- The fallow may have weedy vegetation growing during most of its period but it should be removed or cut after each rainy season to avoid excessive moisture loss or removed before the crop is planted. Moreover, the physical conditions of the soil should be conducive to water storage. Ley pasture using legumes such as stylo (verano, townsville) or other legumes is an effective method for improving fallow lands. The legumes can be planted in pure stands or mixed with grass (maximum one third of grass) after a rough ploughing or along ripped lines (conservation tillage) if ripping is used.
- Bunds should also be constructed to collect additional moisture and control runoff. Grazing should be avoided or controlled.
- The fallow should not be covered by tall grasses and weeds that have an high evapotranspiration rate and thus reduce the moisture content for the crops. Therefore, vegetation growing in fallows should be cut and left decaying in situ (mulching). This also would significantly increase the water storage and shorten the fallow period.

Convert fallow into well managed crop land:

Ley cropping is an effective measure to convert fallow lands into sustainable cropping and restore both moisture and nutrient contents faster and effectively. Once the land is cultivated, a proper rotation with legume crops, compost and manure applications, and adequate management of crop residues may be sufficient to keep the land under cultivation.

For other specifications refer to the measures described above.

SOIL MANAGEMENT PRACTICES

CONTOUR CULTIVATION

Definition and scope

Contour cultivation and planting is a practice of ploughing and planting crops along a contour line as opposed to along the slope. Contour cultivation and planting increases the contact time between water and soil, due to the contour cultivation and/or vegetative barriers checking the flow of water. By modifying the surface conditions it contributes to slow down runoff and reduce erosion.

Technical specifications

- In gentle slopes (<8%), ploughing and cultivation along the contours was found to reduce soil loss by 25-50 percent compared with cultivation along the slope (up-and-down). Within this range of slopes, this technique is effective during heavy storms only if supplemented by strip cropping and possibly contour bunds.
- Contour ridging is generally ineffective as a soil conservation measure on slopes steeper than 8%. In dry lands, with the possibility of heavy rainstorms, the measure is really effective only if combined with bunds and other measures. Greater storage of water and more effective erosion control can be achieved by connecting the ridges with cross ties, thereby forming a series of rectangular depressions which fill with water during rain (see tie-ridging). Contour cultivation is normally used on well drained soils; if applied to clay soils, waterlogging is likely to occur. If excess moisture is expected on poorly drained soils, the contours should be graded to drain excess moisture to waterways.
- This practice is simple and cheap, except for additional draught power, time and labour required to cultivate along the contours. Sometimes, this could be a serious limitation from the farmers point of view.

COMPOST MAKING

Definition and scope

Compost is a natural product which consists of a partially decomposed mixture of organic residues: crop residues, weeds, waste vegetable material, usually mixed with animal dung and some soil. Compost is used for fertilizing and conditioning the soil. Composting is the process of decomposition or breakdown of organic waste by a mixed population of micro-organisms in a warm, moist and aerated environment. The final product of this process is called compost or humus. A good compost contains a proper mixture of available nutrients for the crops and well decomposed materials which would release nutrients gradually during the entire crop cycle and bind soil particles into stable aggregates. The application of compost would improve soil fertility, water storage and reduce runoff.

Technical specifications

Process of composting: Once the plant and animal residues are filled in the compost heap or pit, the process of decomposition starts. This process need MOIST, WARM AND AERATED environment for desirable breakdown.

The breakdown of organic matter during composting is a constantly changing process:

- **Microbial process** brought about by the activities of a succession of various groups of microorganisms (bacteria, actinomycetes, fungi, yeast s, algae, protozoa, mites, ants, termites, worms, etc.)
- **Biochemical reorganization** of the carbon fraction of organic matter (transformation of sugars, starches, proteins, pectines, cellulose, hemicellulose, lignin and ashes)

Figure 56 below shows how the process of decomposition of organic wastes takes place in a given environment.

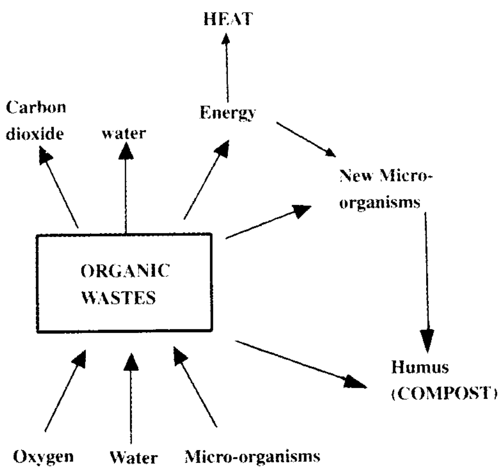


Figure 56

How to prepare compost?

(1) Selection of the composting method

Basically there are two methods for the preparation of compost: a HEAP or STACK and a PIT method. Each method has some advantages and disadvantages.

Comparison between methods of composting:

Heap Method

- can be made in the open, less labour required.
- moisture, temperature and aeration in the heap can be easily controlled because the heap is exposed. However, in dry zones evaporation is high and heaps should be protected.
- no problem of excess of water because the water is drained out freely.
- the heap is easy to turn and mixed for aeration (necessary to accelerate the breakdown).

Pit Method

- labour is required for digging the pit(s).
- moisture, temperature and aeration are difficult to control. However, in dry climate and high temperatures, pits needs less watering and keep moisture longer.
- the problem of waterlogging can easily occur, especially during the rainy season excess of water reduce the breakdown of organic residues.
- more difficult to turn and mix for aeration (more labour requirement).

The pit method can be recommended in the following circumstances:

- In dry areas with shortage of water supply
- In nurseries

However, the heap method under shade, with a shallow pit to retain moisture and a thick cover of straws to avoid evaporation is the simplest and likely most effective method for composting under the Dry Zone conditions.

(2) Site selection for compost preparation

- For site selection of compost preparation, the following criteria should be observed:
- Look for a site located under a natural shelter (trees, live fence, wind break, etc.).
- If a natural shelter is not available, a light and simple roof should be constructed with the materials available in the field (grass matting, toddy palm leaves etc,). The shelter will improve the composting process by reducing moisture loss through sun and wind, especially during the dry season.
- As much as possible the compost site should be located near the water supply to economize on labour.

(3) Selection and collection of organic residues

- Virtually any organic waste of plant or animal origin will decompose in a compost pit, but the time required for decomposition will be different: fresh green material breaks down very quickly, dry straws and woody material takes longer. On the other hand, because of different contents of cellulose & lignin, crop residues from legume crops (pulses) decompose quickly (low content) whilst crop residues from cereals more slowly (high content).
- Composting always proceed better when a variety of organic wastes available from the field and homestead compounds are used rather than just a single source of organic material. Mix organic waste from different sources, for instance legume and cereal

crops, dry grasses from closed areas and marginal lands, freshly cut grass, thin branches and twigs of trees with leaves, fallen tree leaves, husks, shrubs and weeds.

- Not more than 20% of fallen tree leaves should be used, because a higher percentage of dry matter might reduce the decomposition rate of other waste. Remember that items like: polythene bags, glasses, plastics, pottery, pieces of metal or wire, rubber or any inorganic materials will not break down to form compost, and therefore should not be used for compost making.

- The addition of small quantities of other materials to the plant residues are beneficial in speeding-up the composting process and in improving the quality of compost. Common materials are:

  ⇨ ***Animal manure and urine*** (from cows, sheep, goat, pigs, poultry etc.) provides the micro-organisms for speeding-up the composting process. It also enrich the compost in nitrogen, phosphorus and potassium (NPK).

  ⇨ ***Ashes*** (from burning weeds or fuelwood) will enrich the compost in phosphorus and potassium and increases the population of microorganisms.

  ⇨ ***Soil.*** The soil help the composting process by introducing soil micro-organisms (catalyst).

  ⇨ ***Chemical fertilizers*** (only if available). The addition of the nitrogen fertilizer is desirable to speed up the breakdown of cereal straws. The phosphorus fertilizer is desirable to increase the population of micro-organisms responsible for decomposition (the phosphorus fertilizer can be replaced by the addition of ashes).

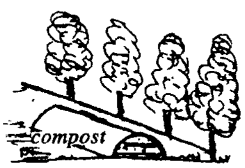
  ⇨ Improved yiests, strains of micro-organisms, worms (not common under dry zone conditions).

(4) Procedure for compost preparation

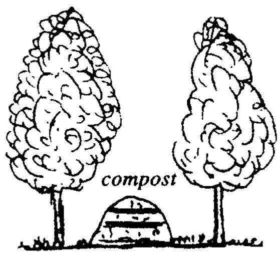
To select the most appropriate method of composting see first the comparison of the two methods given above and decide the most suitable method for your area. Compost making by the heap and pit methods is described below.

Heap method

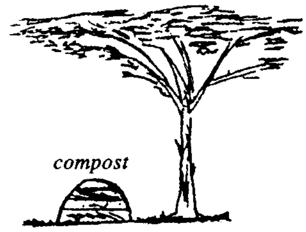
(i) Select the appropriate site for compost preparation under a shelter and near a water supply (if possible).



Under the shade of a live-fence



Under the shade of a group of trees

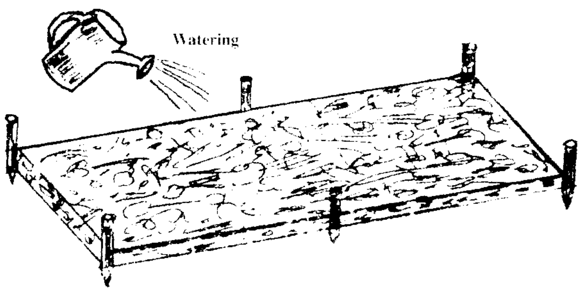


Under the shade of an Acacia,Ficus Or other three

(ii) Collect organic waste, animal manure and ash (from kitchens). To carry the materials use a stretcher or a bullock cart.

(iii) On the site demarcate the boundaries of the heap using wooden pegs. The size of the heap depend from the organic waste but it should not be wider than 2 m and 1.5 m high, and as long as necessary. Then dig a shallow pit (1' deep) for collection of leached nutrients and moisture.

(iv) Within those boundaries a first layer of residues is spread on the surface (layer of about 20 cm thick). The first layer is compacted down firmly and watered properly.



(v) The next step is sprinkling of ash over the compacted layer of plant waste. Half kilo/ square meter/layer will be enough.

(vi) Then the farmyard manure (FMY) is spread. A good amount of manure would be three-five kilo/square meter/layer (one full spade per square feet).

(vii) Some soil should be also spread. Few spades of soil for each layer will be enough.

(viii) Repeat the same procedures as explained in step iv, v, vi and vii until the heap reaches to about 1.5 m (5 feet) high.

To improve the aeration in the heap, bamboo or other sticks should be placed standing in the middle of the heap at every 2 m (6-7 feet) spacing along its length.

A diagrammatic cross section of the heap showing the layers is given in the figure 57 below.

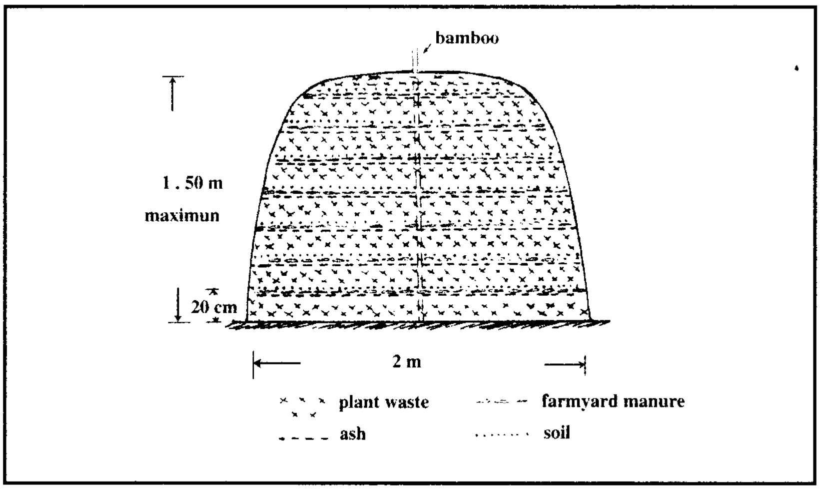


Figure 57 Cross section of a compost heap

(ix) Cover the heap with dry grasses or other residues. The sides of the heap can be also covered with soil to keep the heap warm and to avoid drying by wind.

(x) The heap is now left for 3 to 5 weeks. During this period and at least once a week, the moisture should be checked. If the heap is dry, water should be added. Remember that the heap should be always moist, never dry or wet.

(xi) After 3 - 5 weeks the compost should be turned and mixed in order to aerate the heap. This aeration speeds up the composting process by increasing the population of aerobic micro-organisms.

Repeat the operation mentioned in (xi) above for 1 to 3 times at the same interval and let the COMPOST MATURE. If the above steps are respected and properly done, the approximate duration of the composting process, from the starting date of preparation until the compost is mature is 3-5 months. The time required will also depend on the type of plant residues used.

The **maturity of compost** is assessed by the appearance of organic residues, i.e. a mature compost have to show **a good homogeneity in colour (black) and in texture (light in weight and spongy appearance).**

If the compost is not going to be used immediately, it is recommended to cover it so that rain does not leach out the soluble nutrients. The watering should obviously stop.

Pit method

Follow the steps (i) and (ii) given in the heap method.

(iii) Demarcate the boundaries of the pit. The size and number of pits will depend on the amount of plant material available, but in any case the pits should not be more than 2 m wide, 4 m long and 1.5 m deep (6 x12 x5'). Start with digging 2 pits, one next to the other as shown in the figure below.

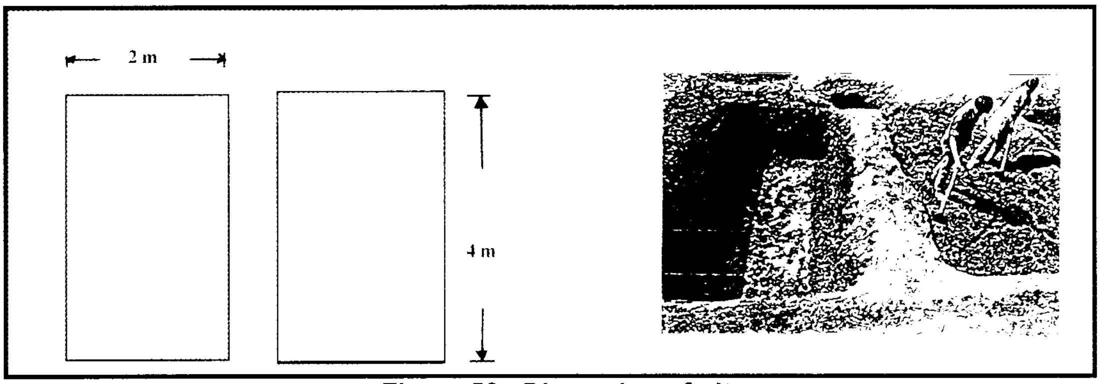


Figure 58 Dimension of pits

Start with the first pit and follow the steps (iv), (v), (vi), (vii), (viii) given in the heap method.

(ix) When the pit is full, cover it with dry grasses or other dry residues.

(x) The pit is now left for one month and it is watered every few days for the first week and once a week during three weeks according to need. Keep the materials moist, not wet.

(xi) After a month it is time to turn and mix all the compost into the second pit which was dug next to the filled pit.

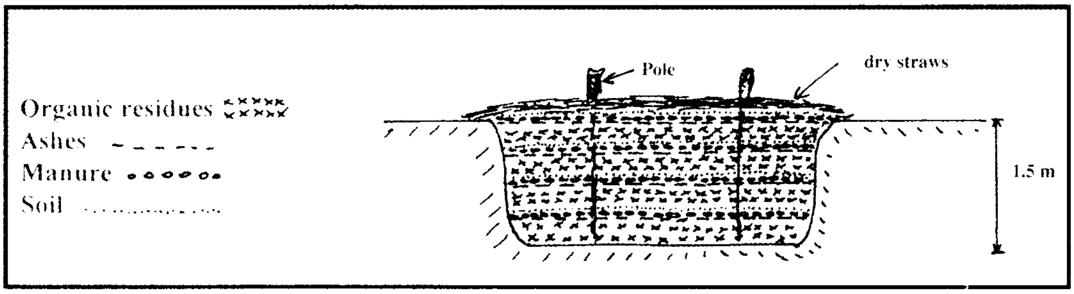


Figure 59 Cross section of pit showing the layers

(xii) The compost should remain in the second pit for 3-4 months. In this time the compost is expected to be mature and ready for utilization.

(xiii) Refill the first compost pit one month before the end of the composting process taking place in the second pit and repeat the same procedure. By this system you can produce compost three times a year (see figure 60) or more if the time of decomposition is faster.

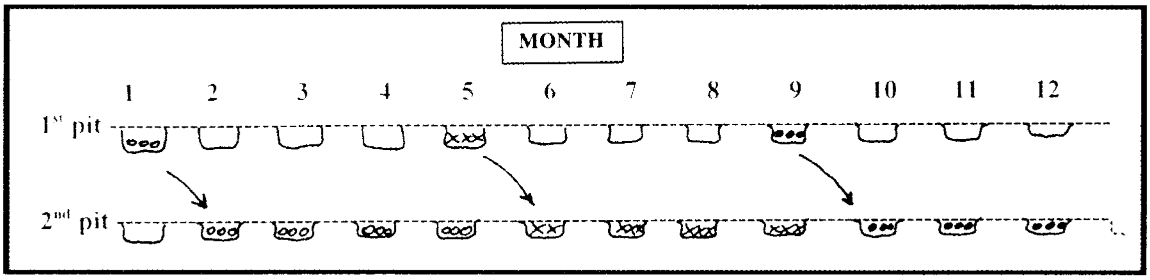


Figure 60 Sequence of composting using 2 pits - 5 months total (1+4) decomposition

(5) When should compost be prepared?

The compost should be ready when it is needed in the field or in the nursery (e.g. sowing time, seed bed preparation, soil preparation for seedlings in polythene tubes, etc.). Depending on the available plant residues and water, compost can be prepared throughout the year and kept under shade or in bags for future use. The amount of residues and other waste may increase by the regeneration effect generated from the implementation of several SWC measures in closed areas, plantation sites, reclaimed gullies, etc.

Inputs for compost are mainly labour and water. Water is not easily available in several villages of the dry zone, and thus composting should take place not later than October-November.

Integration is with every other possible physical structure and agronomic measure intended to improve yields as well as protect the soil. Compost is an excellent technique for improving soil structure, fertility and water storage capacity (see above chapters on effect of organic matter).

Training of farmers is important, with particular emphasis on layout, watering, sheltering, conservation and utilization of compost in the field. In this respect compost should not be left at the surface of the field and exposed to high temperatures (mineralization of the OM) and wind erosion for a long time. It should be incorporated within the soil profile immediately.

Limitations in the Dry Zone are expected on the water availability side, particularly around the homesteads; on the amount and quality of residues and the labour required, in particular for the pit method. In each area these factors should be taken into consideration before starting composting.

EFFICIENT USE OF FERTILIZERS

Definition and scope

Although the importance of organic manure in increasing cereal yields is well recognized, it is unlikely that there is sufficient available, on a regional basis, to sustain yields without the use of additional chemical fertilizers. Nitrogen levels may be maintained by using legume crops or pastures in rotation but even then further inputs of nutrients are required to replace those removed by the crop (Fussell - 1992).

In dry zones the rational application of fertilizers is then often necessary to support and enhance a balanced growth of crops. However, in dry areas the application of fertilizers is a delicate operation.

An excess of fertilizer application, particularly N fertilizers like Urea and Nitrates can affect the growth of crops if levels of soil moisture are not sufficient to regulate the ion exchange mechanisms occurring into the soil. Excess of ions concentration in the exchange complex would drag out moisture from crops in order to dilute the high concentration of solutes (osmotic pressure) and thus burn the young plants in a very short period of time.

A high concentration of N speeds up the growth of crops, i.e. the production of an high amount of foliage and soft tissues that would not stand the consequent high levels of transpiration against the limited water reserves of the soil. A dry spell of a week or two may then kill the plants.

Farmers in dry zones are therefore very cautious in applying N fertilizers, normally in small doses at a time or in one small dose at the beginning of the rainy season (after a good rain). Phosphorous does not have such problems and is applied in various forms (mainly Triphosphate under Myanmar conditions) before sowing. Phosphorous is not mobile and remain trapped in the exchange complex, which will release Phosphorous to the plants gradually as per their needs.

The N fertilization is mainly directed to increase biomass and grain production whereas P is essential for the quality of foliage, the photosynthesis and the reproductive stage, the filling of seeds and tubers, the development of the root zone and resistance against climate adversities and pests. Both elements, if properly used and integrated with physical and biological measures can enhance the cover of the soil and reduce soil erosion.

In turn, soil and water conservation measures allow fertilizers to be used with less risks of leaching, loss and wilting/whitering, especially in case of N applications. This because fertilizers are generally distributed over the soil surface, generally staying within a thin layer of few cm of the soil profile. Then, serious sheet and rill erosion would significantly reduce or even render ineffectual the application of such inputs. Therefore, the integration with soil and water conservation measures is of great value.

Technical specifications

The application of fertilizers should be guided by the following key elements:

- **P fertilizers distributed at a rate that is economically convenient and in relation to the type of crops and plant density, soil type and moisture conditions.** Besides

F-.

its positive effects on cereals, P is also important for legumes, improving their root system, nodulation and reproductive stage. In this respect, they are useful to improve the effectiveness of systems such as ley cropping that emphasize on legume pastures and other agronomic measures aiming at improving the biomass and organic matter content of the soil.

- **N fertilizers should be applied with care, particularly where water is a main limiting factor and where no other conservation measures are applied.** Small doses applied in two to three times should be the norm, mostly based on farmers experience rather than scientific rules. In areas where additional measures are able to guarantee a sufficient supply of water, N can be applied at higher doses, but being careful to balance the amounts with plant density, and always being careful not to exceed because early abundant rains may not be followed by similar amounts in the middle of the season or at the filling time. In this case, and as said before, an high amount of photosynthetic biomass would need considerable amount of water to sustain itself and then may suffer from water deficits.

Limitations relate to fertilizer costs and risks connected with climate conditions. The drier the conditions the more risky fertilization becomes.

VEGETATIVE CONSERVATION MEASURES

GRASS STRIPS ALONG THE CONTOURS

Definition and scope

Grass strips are vegetative barriers made out of grass planted in narrow strips of 0.5 to 1.5 meters width laid out along the contour. Grass strips control erosion rather effectively in gentle slopes but above 3-5% slope their effect decreases. While contributing to protect soils against erosion they also provide valuable biomass meant to increase animal feed or used for different purposes (roofing, essences). Grass strips cause less interference than other measures as they can easily be crossed by oxen and plough. Moreover, grass strips take out little amount of arable land and hence would not reduce crop yield. **Cost of construction and maintenance is much lower than physical structures.**

However, in dry areas grass strips are less effective in reducing runoff as they provide little storage capacity. Although they retard the movement/velocity of water and encourage infiltration they do not offer much resistance against erosive rainstorms, particularly at the beginning of the rainy season because the new shoots are not yet developed. Besides, they are easily overgrazed and damaged by animals.

Technical specifications

Grass species should be perennial and persistent, compete with and suppress weeds, provide good ground cover, slow down the water flow and hence conserve the soil and moisture. Besides, they should **provide valuable fodder or other materials of use by the farmers.**

In terms of layout, grass strips are established along the contour. Grass strips are established on a 1m vertical interval, i.e. at 3% slope the distance apart two strips is 33 m and decrease to 7 m at 15% slope. In dry zones, grass strips should not be established above 5% slope. For slopes up to 15% they may be planted alternatively with bunds (one grass strip/one bund).

The **width** varies from half to one metre or more depending on the density of the plants in the strip. For conservation purposes a **width of 1 m is recommended.** The width of the strip depends on the density of the grass vegetation in the strip. When the line of grass is continuous and close it does not allow much soil to pass through, but filters out and deposits it in the upper slope of the strip. In this case, the width of the strip can be narrow. But if the plants in the strip are sparse and do not allow major deposition above the strip, the process of filtration and deposition of the soil particles would be gradual and takes place throughout the width of the strip. In this case, wider strips allow more deposition of soil particles. **However, it is always preferable to use narrow strips since narrow strips are believed to be nearly as effective as the wider strips, provided they are well established and dense.**

The strip is established by **broadcasting or sowing/planting seeds/splits/cuttings in two or three lines.**

When planting is done in three lines/rows the **middle row can be sown with a legume** to improve the nutritive value of grasses. If the broadcasting method is used, grass seeds can be mixed with the legume seeds and broadcast in the strip.

For direct sowing a **fine seedbed preparation is required.** Most of the seeds are small and large clods may hamper germination. Depth of planting is very important for forage seeds because of small seed side. The principle the smaller the seed the shallower the depth of planting should be observed. Generally, 0.5-1.5 cm depth is the optimum for most species. When planted manually, rows are opened with a stick at the desired spacing and seed is drilled in the row. Seeds are covered with a thin layer of soil and pressed hard to the soil. **Before planting, seeds should be checked for their germination.**

When splits and/or grass cuttings or seedlings are used, planting is done in lines/ rows. In this case, attention should be paid to the spacing between the plants. Discontinuity between the splits/seedlings/cuttings will result in serious reduction of infiltration and deposition of soil particles. Spatial discontinuity should be avoided by bridging gaps and improving the planting technique.

Good quality planting material, timely planting and proper management are key factors for the establishment of grass strips.

Spacing between the seedlings/splits should not be wider than 10 cm to guarantee a dense and effective grass strip.

- In dry zones it is preferable to plant grass strips using splits instead of direct sowing, saving considerable time for the establishment of the rows, suffer less competition from local grass, cover the soil faster and take advantage of the rains more effectively. Planting material should be available from nurseries or from farmers that can produce grass under supplementary irrigation. At the time of planting, the handling of planting materials is very important. The grass is cut at about 12 cm above the ground, then the clump is uprooted and transported to the planting site. The clump should be transported and kept under damp conditions to avoid desiccation before planting. At planting, the clump is split into pieces including 2 to 3 tillers each to ensure a good establishment (fig. 61). The higher the number of tillers in each piece, the better the establishment of grass strips. The roots should also be carefully uprooted and handled to prevent damage to the roots and growing points. Legume seeds planted in the middle row should be sown by using seeds.
- Planting should be carried out at the onset of rainfall, when the soil is not too wet or too dry. Planting should always ensure good soil-seed/seedling contact by pressing the sides of planting material.
- **Harvesting** of grasses depend from their use and inner characteristics. Some grass should be cut frequently and at a young stage, other at flowering or filling time etc. If used as forage usually the first harvest is after 3-4 months from establishment, before flowering and cutting grass 10-15 cm above the ground.
- **Species should not be aggressive on adjacent crops and act as weeds.** There are number of grass species that can be effective in grass strips, such as Rhodes, Andropogon sp., Setaria sp., etc. But also native grass (see bund stabilization, page 271) which may be more adaptable to local conditions and tolerant to drought. Besides, the advantage of using native grass species is that land users are familiar with the purpose and management of such grasses. Regarding legumes, species such as stylo, sirato and desmodium should be tried.

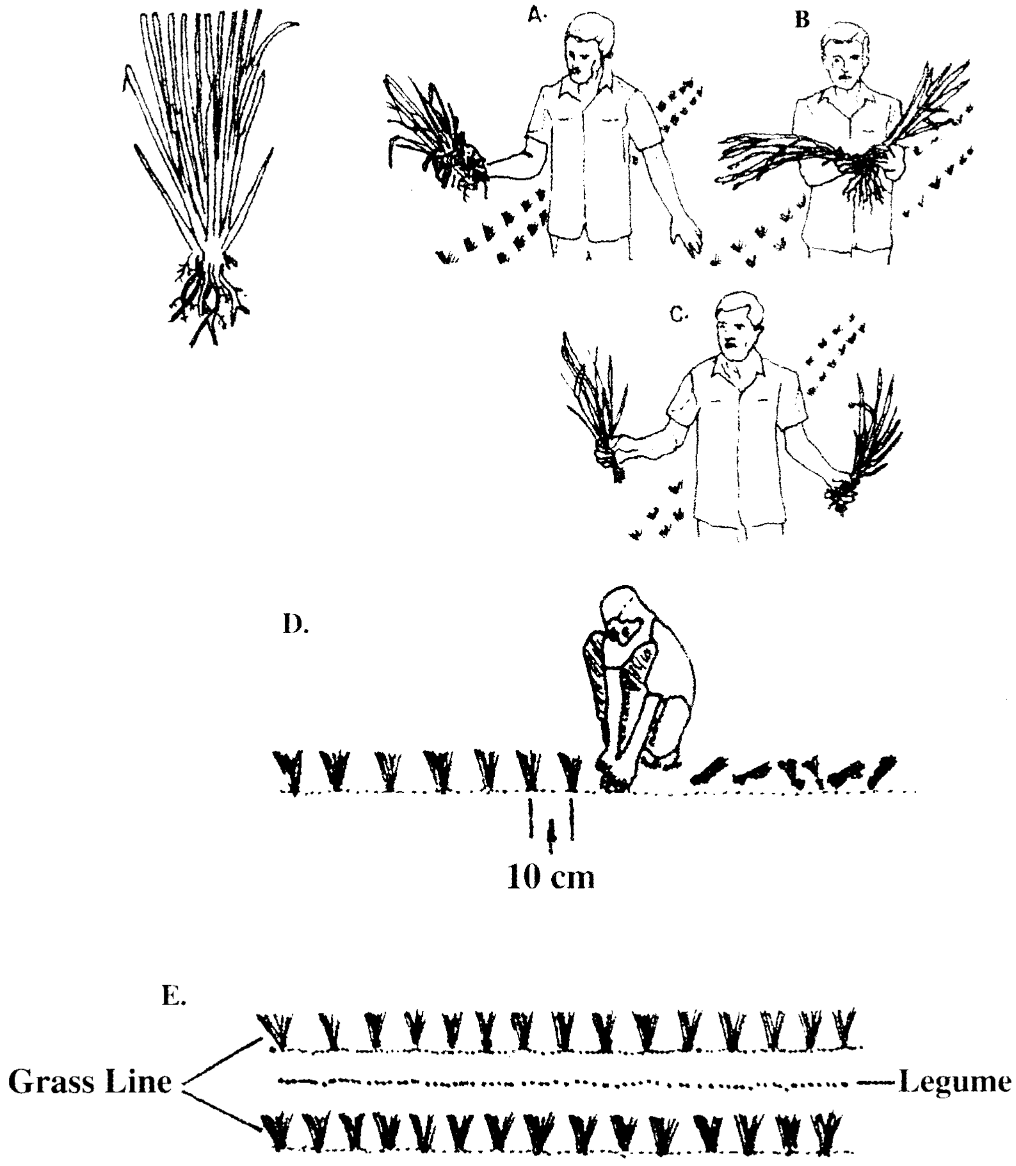
- Grass should be cut regularly and possibly harvested before they seed. However some grass are aggressive with rizoma and stolons which rapidly colonize the surroundings. In all circumstances, forage/livestock and agronomy specialists should be consulted prior to the selection of this technique.

- **The establishment of grass strips is normally constrained by numerous limitations** such as the free movement of animals, particularly during the first year; the limited effect on moisture conservation in dry zones and the continuous management it implies. However, there is considerable scope for grass strips as an alternative to bunds, particularly on gentle slopes, well drained soils and areas benefiting from higher rainfall.

- ***Training*** **of farmers is essential before planting, including the proper management of the strips.** ***Inputs*** refer to grass seeds or planting material. Some species may have to be purchased and then multiplied first. Fertilization is also advantageous and may take place in nutrient depleted soils. However, low ***fertilizer applications*** are normally required for grass compared to crops. ***The work norm*** is tentatively, estimated at 1-2 person/acre of grass strips.

Sowing grass stips (drilling)

After 3 months in between crop



Steps in obtaining and Planting root splits;
(A) Clump of grass , (B) Splitting the clump ,
(C) Grass splits , (D) Planting the splits and
(E) Planted grass splits of two lines with one line of legume in the middle.

Figure 61 Grass strip establishment (split method)

STABILIZATION OF PHYSICAL STRUCTURES

Definition and scope

Stabilization refers to the planting of crops, grass, shrubs and trees in different combinations in order to strengthen the resistance and stability of physical structures such as bunds, trenches, checkdams, SS dams, etc., against rain drops splash effect, runoff and cattle trampling. At the same time, stabilization has the purpose of making productive the surface area occupied by the structure itself, which is particularly important for soil bunds on cultivated land.

Stabilized structures would need less maintenance and damages are less likely to occur, even during heavy rainstorms.

Trees or shrubs (pruned to avoid shade) help to demarcate boundaries and thus provide additional sense of ownership.

Particular plants are also hosts for friendly insects able to control pest incidence.

Stabilized areas are an additional source of timber, fuelwood, fibre, food and forage crops, palatable grasses & legumes, fruits and other products (dyes, gum, medicinal, etc.)

Technical specifications

- For practical reasons, the term bund stabilization is intended to include also the revegetation of trenches and other water harvesting structures used for forestry, terraces walls or risers, cutoff drain and waterway embankments. **In this respect, bund stabilization apply to all physical structures.**
- In dry zones, bunds are often stabilized for 1-2 years with annual and semi-perennial crops because of the water harvesting effect along the edge of the bund embankment. However, part or all of the bund length should be stabilized with forage grasses and legumes, particularly after 1-2 years from the construction period.
- **Soil bunds are more difficult to stabilize than stone faced/soil bunds.** In the first year and for a few months period, soil bunds are not very stable and stabilization would need to be accurate. Normally, **grass should be planted in rows at the foot of the downstream side of the bund and at the level of the berm.** Grass should be planted by using the split method (see grass strips) which will speed up the stabilization process. If planted on top of the bund or throughout its entire area, grass should be combined with 1-2 rows of legume.
- The **flat top** of the bund can be planted either with grass/legume or with pulses, shrubs/ trees such as Pigeon pea, Sesbania sp., or Leucaena Leucocephala. **The trench before the bund** can be planted during the first 1-2 years with waterlogged resistant (Sorghum, Pigeon pea, etc.) crops or vegetables. Other crops (sunflower, chick peas, etc.) may even be planted on the residual moisture at the end of the rainy season (relay cropping along the bund).
- However, **after the formation of a bench terrace**, the small embankment which is normally located at the edge of each terrace, should be stabilized with trees and perennial shrubs. The lower part of the terrace would be then stabilized with dense grass, particularly in absence of a stone wall/riser.

- **Stone faced/soil bunds are more stable and can be vegetated easily.** Natural grass would occupy the empty spaces between stones and within few years the entire structure is strongly and tightly stabilized (binding effect). In this case only the top of the bund can be stabilized with improved grass/legume/trees/shrubs. Crops on top of the bund may be growing only during the first year because bunds would become too compacted to allow proper growth of crops.
- **Multipurpose plant species used for various biological measures are also suitable for bund stabilization.** However, there are a number of **local indigenous species** that can be used effectively. Some of them are very palatable and highly valued by farmers. They normally withstand drought better than new varieties. Most of the time valuable grasses are overgrazed and thus seeds are difficult to collect. However, local farmers may be subcontracted to collect seeds from areas that should be temporarily closed to cattle interference. The harvested seeds can then be sorted out, cleaned and germination tested. A multiplication of these grass should take place in farms, nurseries or research stations where the possibility of supplementary irrigation exists. Then, after one or two years, there would be sufficient capacity to respond to the bund stabilization needs of a wide area.
- **Revegetation of cut off drains and waterways** follows the same principles. However, perennial grass are recommended for maximum stability. Waterways should be planted with trailing type grasses such as Kikuyu (Pennisetum clandestinum) and couch (Cynodon dactylon) which spread with stolons and can stand temporary waterlogging. These species are generally planted with cuttings at a space of about 20 cm.
- **Inputs** required are only seeds or vegetative material, most of which would be provided by the farmers themselves or by nurseries and grass multiplication centers. Grass growing on bunds should be cut regularly, at the time grass has its maximum nutritional value (depends from varieties but around flowering time). Low **fertilizer applications** would be useful to enhance the growth of plants, particularly during the first rainy season. Work norms for bund stabilization are similar to those estimated for grass strips. However, this activity should be considered a self-help effort and thus work norms are just indicated for planning purposes.
- **Integration** naturally occurs with physical structures. Management and maintenance included control grazing and cut and carry of produce, filling of gaps, pruning of shrub/ trees etc.
- **Training** is necessary for the handling and management of trees/shrubs, improved grasses, seed collection and multiplication, harvesting and storage, etc.
- Limitations are mostly related the free movement of animals which should be restricted for at least one year for trees/shrubs and/or grass and legume establishment. Examples on how stabilization should be undertaken

The following examples should be considered flexibly since there are countless number of species and arrangements which are possible to implement based upon farmers' knowledge and desire.

(1) First agree on the type of species, their purpose, their combination (if more than one), arrangement (one row or more, staggered, etc.), planting technique, care and management.

(2) Make sure planting material will be available (from farmers, external source or both) on time and in optimal conditions (seeds, seedlings, saplings, cuttings, grass splits, etc.).

(3) If necessary provide training on management of species unknown by farmers.

1. Stabilization with Trees and Shrubs

Trees and shrubs are ideal means to stabilize physical structures, particularly bunds constructed on cultivated fields or grasslands.

Trenches and other structures are already meant for tree planting and thus should be stabilized with either crops or grass & legumes.

Most trees described below are described as trees/shrubs based upon the purpose they are planted for and consequently the various degree of pruning and coppicing they are subjected to (for example Leucaena sp. can grow a tall tree or become a shrub with a high mass of foliage if pruned short and pollarded regularly).

Steps

(i) **Tree species should be selected together with the farmer:** they may be single species or more species in different combinations, single purpose oriented or multipurpose, planted at regular or irregular spacing, etc. Remember that farmers do not like shading to their crops and competition for water and nutrients, thus species should be selected with care. Better select species with rooting system that penetrate soil deeply and break hard pans than species that spread roots laterally (in this case lateral/side root pruning may be necessary).

(ii) **Prioritize the bunds farmers want to stabilize.** Most likely they will be willing to plant trees on boundary bunds first and then, if beneficial, also on the bunds across open fields.

(iii) **Agree on the spacing apart trees/shrubs** based upon the type of tree and its purpose.

(iv) **Proceed to plant trees on:**

The **space between the berm and the collection ditch** (simplified as berm space) in case of soil bunds and double stone faced soil bunds, occasionally also at the lower side of the bund if dense double rows are intended to be planted.

At **the foot of the lower and/or upper side** of stone bunds.

1.1 Trees/Shrubs for Fodder Production

Planting technique :

- They should be planted at **close spacing**: 1' to 3' apart on single or staggered double row (one on the berm and the other at the lower side of the embankment).
- **In dry zones plant the trees/shrubs using seedlings instead of direct sowing.** Seedlings grow faster and by the end of the rainy season have a rooting system able to explore wider and deeper portions of the soil profile and thus have a better chance to withstand the long dry season. In case of direct sowing, the trees planted on the berm have better chance to survive than the others planted at the foot of the bund (less moisture).

- **For forage production preferably select nitrogen-fixing trees/shrubs** such as Leucaena Leucocephala, Gliciridia Sepium and Sesbania Sesban.

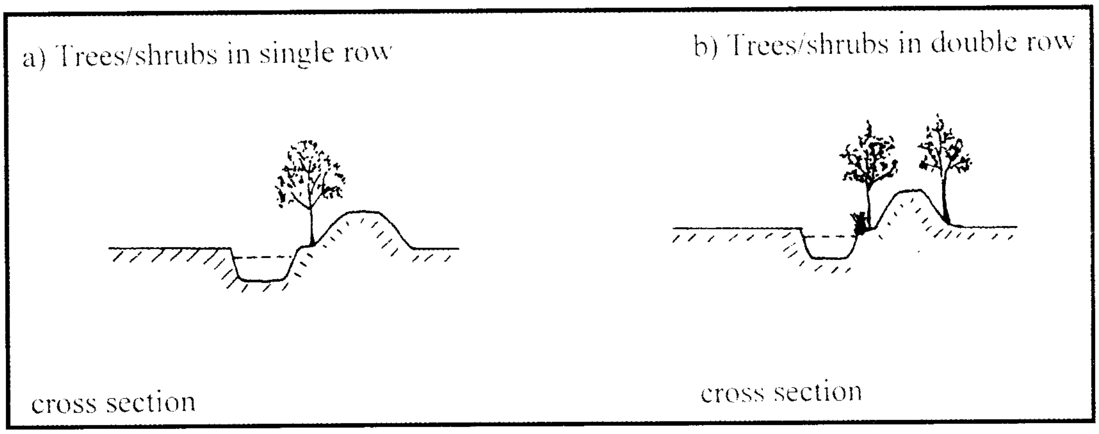
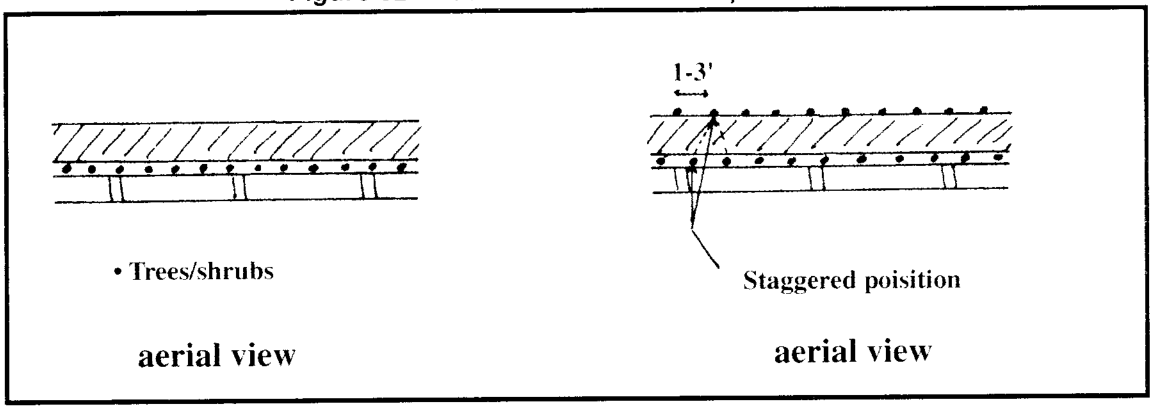


Figure 62 Trees/shrubs for fodder production



Management:

- After one year establishment, and right at the beginning of the rainy season, **prune the tree/shrub 3' from the ground** to avoid competition with crops (shading, moisture).
- Second year pruning keep the trees/shrubs low (max. 6') by regular pollarding and lateral pruning during the growing season (every 6-8 weeks depending on species).
- After 2 or more years **lateral roots may be pruned** to avoid competition with crops.
- **Consult livestock specialist on how to use trees/shrubs leaves.** For instance Leucaena leaves and pods contain mimosine, a substance which is toxic to livestock. Hence, leaves and pods should be mixed with other grass in various proportions depending on the type of animals going to be fed. Some tree/shrub species need few days wilting and drying before cattle eat it.

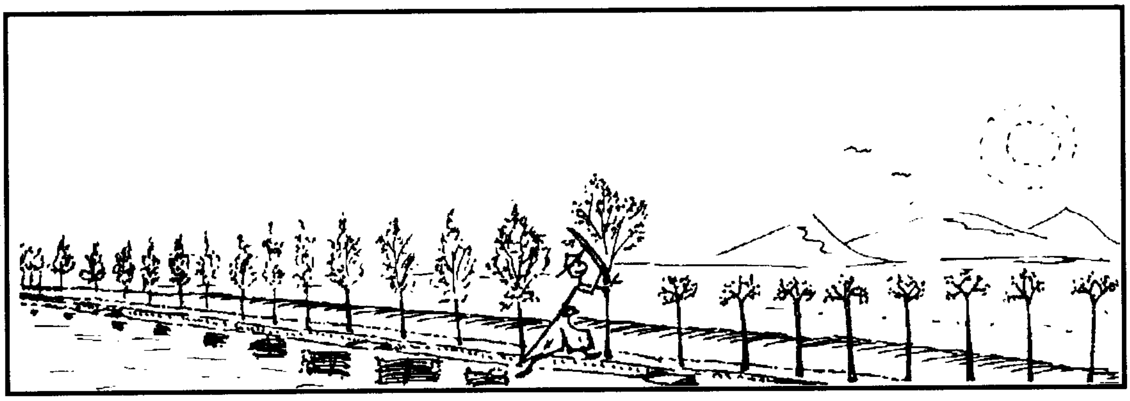


Figure 63 Example of pollarding (removal of most of the crown)

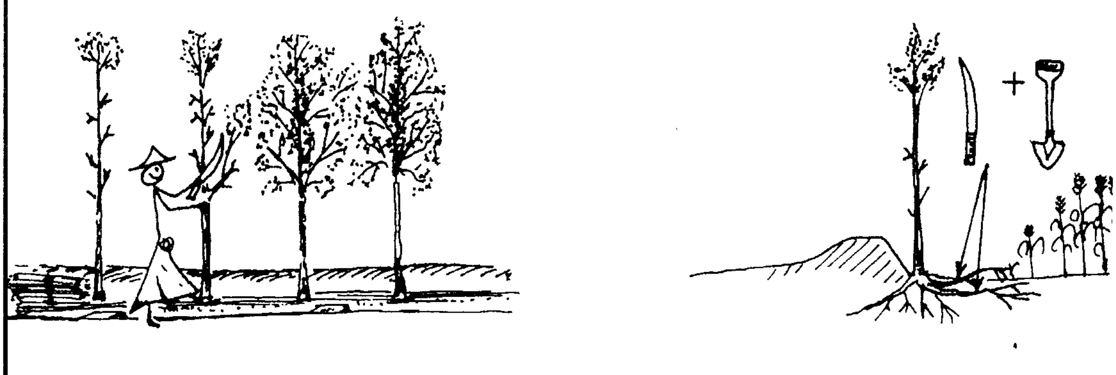
1.2 Trees/Shrubs for Fuelwood and Timber Production

Planting technique:

Usually, **single row** is preferred and spacing between trees is wider (3-12'). Planting with seedlings is preferable. Nitrogen fixing trees are also preferable such as different Acacia species and Acacia Catechu in particular, Azadiracta Indica (Neem), Albizia Lebbeck but also Calliandra, Leucaena L. , Sesbania Sesban and Gliciridia Sepium planted in wider stands (3-6').

Management:

- After 1-2 years from establishment and before the crops growing season, branches and foliage should be reduced by side pruning to avoid shade and competition for nutrients and water.
- **Root pruning** may be necessary after 2 years to avoid competition with crops.
- Most trees are also multipurpose and thus management of each species should take into account additional benefits (forage, dyes, medicinal, gums, etc.)



(a) Purning foliage and branches (b) Root prning

Figure 64 Example of pruning

1.3 Fruit Trees

Fruit trees can be very important for improving the household economy and supplement the diet of the family. In the Dry Zone, recommended fruit trees are custard apple, cashew, jackfruit, tamarind and mango, etc. Fruit trees normally would require sufficient moisture and thus should be planted only on the upper side of the bund (berm) provided with a collection ditch.

Planting and management techniques:

- The spacing apart is often wider to avoid major shading problems.
- It is recommended to plant fruit trees in combination with other multipurpose species (see 1.3) at various intervals (for example: 1 fruit tree - 3 fodder trees, 1 fuelwood tree - 3 fodder trees - 1 fruit tree,...etc.)
- For grafting techniques and management of fruit trees consult forester and horticulture specialist.

1.4 Multipurpose Tree/Shrub Species and Combination of Species

Most trees/shrubs are multipurpose or at least have one main purpose and other secondary and tertiary or more purposes. Based on farmers desire, a combination of different species is recommended. Spacing will be accommodated based upon the type of trees/shrubs and their different purposes. In this respect, there is no specific criteria to follow but a rational combination of planting and management techniques able to maximize the use of different species.

Multipurpose species can be also combined with fruit trees and planted following various stands based upon primary and secondary purposes. Few examples are given in figure 65.

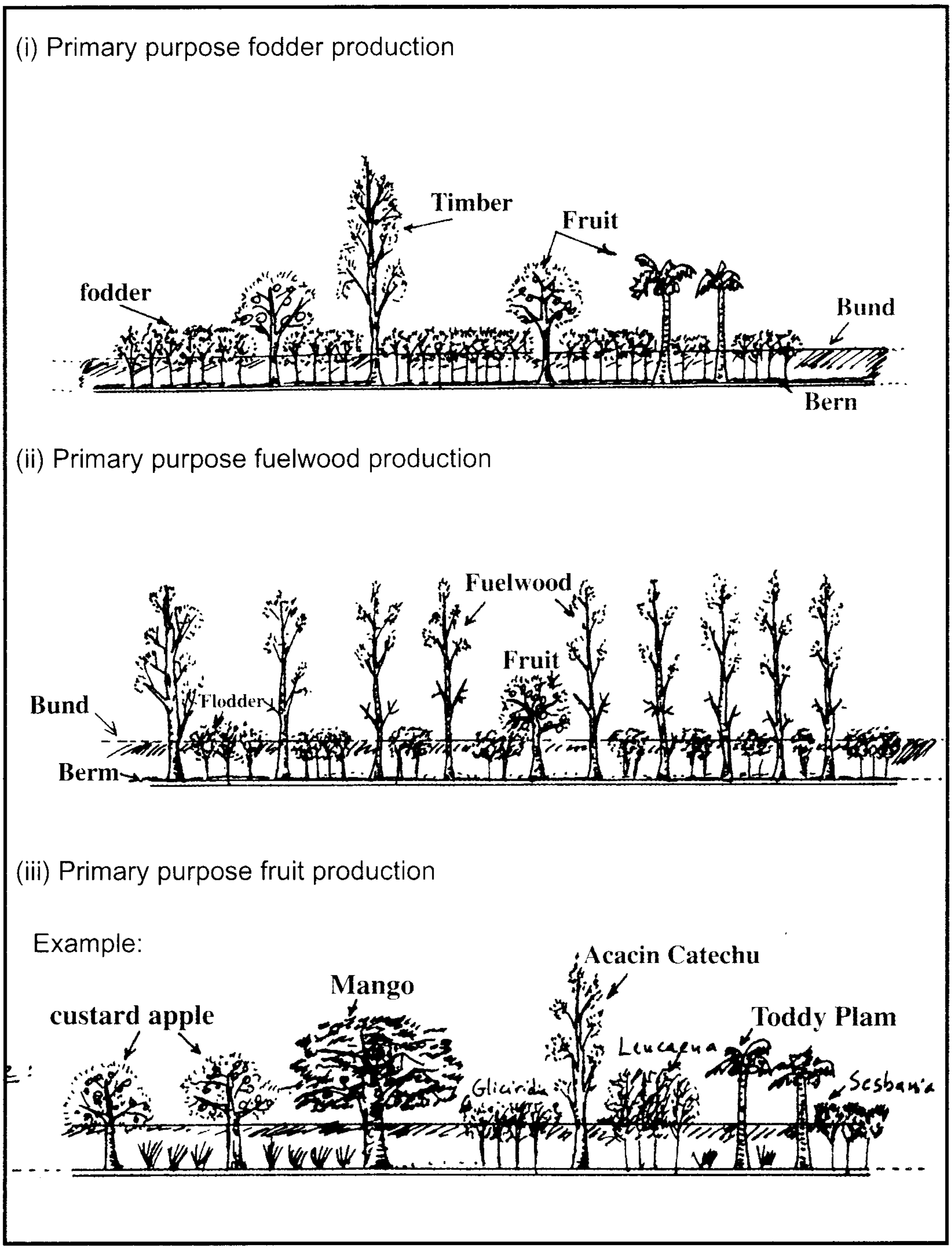


Figure 65 Example of bunds planted with multipurpose trees/shrubs and fruit trees

2. Stabilization with Forage Grass and Legumes

The main purpose is to provide valuable supplementary animal feed and stabilize the bund embankment. All physical structures can be stabilized with grass and legume pasture species. Amongst these, soil and stone faced soil bunds, trenches and herring bones are most suitable for grass and legume stabilization.

Fodder grass and legume species can be integrated with trees/shrubs in different combinations and proportions. Therefore they close gaps between trees/shrubs and make the bund stronger.

Steps

(i) In the Dry Zone several local drought resistant and palatable grass species are available. Fodder legumes growing spontaneously are rare and seeds are available only through government seed multiplication centers or from overseas. Therefore, this section will refer mostly to grass.

(ii) Choose the best type of grass species based upon type of soil, water requirements, palatability and biomass production. They should be planted the same year the physical structures are constructed (soft embankment is not yet compacted and less competition with other species/weeds).

If native grass species are to be used ask the farmers which one they suggest, prefer and have sufficient seeds for planting.

If new grass species are to be introduced consult livestock expert.

(iii) **Test germination rate of seeds.** Germination of 50-80% is satisfactory. If germination is lower (some grass species have 20-30% germination) increase the number of seeds during sowing time or look for another lot of seeds.

(iv) **At the onset of the rainy season plant the seeds** not deeper than 0.7' , preferably 0.5' depth. Use a sharp stick to open a shallow row and drill inside the grass seeds. Then press the soil back to the row so that to ensure a good contact between soil and seeds.

(v) After 1 or 2 months from planting, **weeding** of other spontaneous aggressive vegetation may be necessary to allow improved grasses to establish properly and overwhelm the competition with other species. However, this may be not be a practical suggestion but native grass do normally stand competition well.

(vi) **Grasses should be harvested before flowering, when their nutritional value is high.** However, first year seeding may be allowed to increase the grass population. Harvested grass can be used as green fodder immediately or kept for a longer period through hay making. **Hay making** is a simple procedure that requires the grass to dry under the sunshine for a period of 3-5 days, on a scattered layer not thicker than 5' -10" which is to be turned twice a day. Then bundles can be stored under shade for several months.

2.1 Stabilization with Native Grass

Grass are suitable mostly for trenches and herring bones only if regular cut and carry takes place. On bunds they should be combined with forage legumes or trees/ shrubs species in different proportions.

Type of grass: The following species are recommended in the Dry Zone

1. Myanmar Name: **Myet-le-gwa** › Scientific Name: ***Dactyloctenium aegyptium***
   Distribution and climate: Common in all Myanmar below 4000 ft.
   Fodder: fodder value is low (contains toxic substance).
   Soil: all types, including medium saline/sodic soils but not on hilly sandstone areas.
2. Myanmar Name: **Myet-swe-le** › Scientific Name: ***Themeda triandria***
   Distribution and climate: Common in low and high rainfall areas
   Fodder: good fodder up to flowering stage
   Soil: all except saline and sodic
3. Myanmar Name: **Naya-myet** › Scientific Name: ***Setaria verticillata***
   Distribution and climate: Common in central Myanmar around villages.
   Fodder: medium quality fodder only at young stage and up to flowering stage.
   Soil: all except saline and sodic soils.
4. Myanmar Name: **Wa-yon-myet** › Scientific Name: ***Echinocloa notabile***
   Distribution and climate: Common in central plains of Myanmar. Drought resistant.
   Fodder: good quality fodder only at young stage.
   Soil: all except saline and sodic soils.
5. Myanmar Name: **Padaw-byu** › Scientific Name:***Bothriocloa pertusa***
   Distribution and climate: Very common dry zone grass. Drougth resistant.
   Fodder: good quality fodder both green and dry.
   Soil: prefer fertile soils.
6. Myanmar Name: **Padaw-ni** › Scientific Name: ***Dichantium annulatum***
   Distribution and climate: Common in central plains.
   Fodder: good quality fodder both green and dry.
   Soil: grows well in fertile soils.
7. Myanmar Name: **Myet-swe-le** › Scientific Name: ***Dichantium caricosum***
   Distribution and climate: Common in central plains.
   Fodder: good quality fodder both green and dry.
   Soil: grows well in fertile soils.
8. Myanmar Name: **Myat-sat; Myat-nan** › Scientific Name: ***Cymbopogon virgatis***
   Distribution and climate: Common in uplands of drier parts of central Myanmar
   Fodder: poor quality fodder, eaten only at times of scarcity. Must be fed dry.
   Soil: grows well in all type of soils, including medium saline/sodic soils.

Planting technique

Trenches and herring bones: 2-4 rows depending on the size of embankment and soil type. On poor soils 2 rows are sufficient. On soils retaining water well and of better fertility, 3-4 rows is recommended (figure 66).

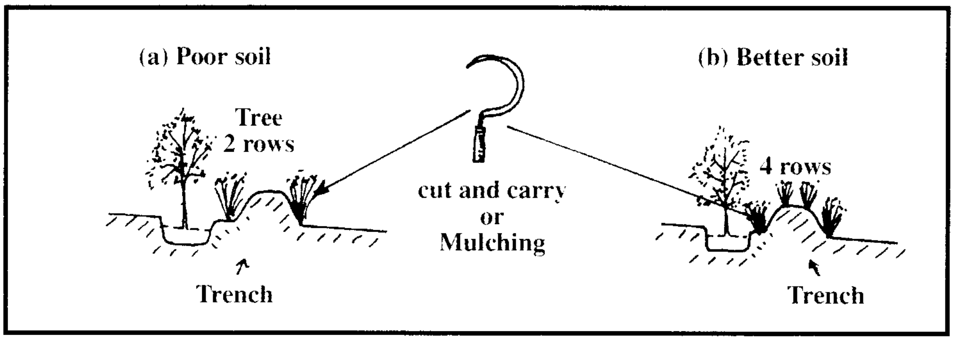


Figure 66

<u>For soil bunds, stone faced soil bunds and stone bunds</u> plant 1-4 rows depending if combined with trees/shrubs and the type of structures (figure 67):

- For *soil bunds* (1-2 rows) if combined with trees/shrubs, with food crops (2 rows), with forage legume (3 rows) or alone (4 rows).
- For *stone faced bunds* (1 row) if combined with trees/shrubs, with food crops (1 row), with forage legume (2 rows) or alone (3 rows).
- For *stone bunds* only 1-2 rows are possible in most circumstances.

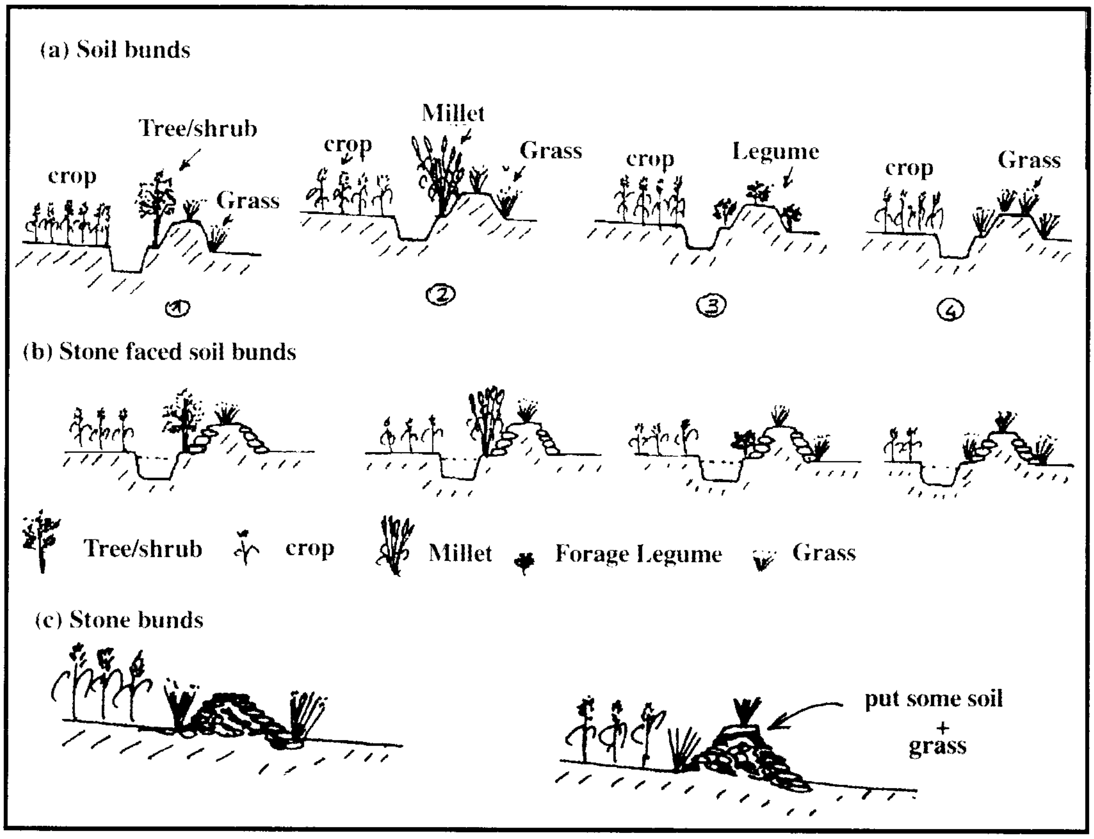


Figure 67

Management

Undertake weeding. First year cut and carry after seeding. Following years cut and carry before flowering and make hay if necessary. Grass can be used to make good compost.

2.2 Stabilization with Improved Grass and Legumes

Type of species: the introduction of new species is to be done with care and at small scale first in order to test their suitability and performance.

Possible Grass	Possible Legumes
• Cenchrus ciliaris (Buffle)	• Macroptilium atropurpureum (Siratro)
• Chloris gayana (Rhodes)	• Lablab purpureus (Lablab)
• Panicum maximum (Green panic)	• Stylosanthes hamata (Verano Stylo)

Combine grass and legumes in different proportions based upon the needs of the farmers (2 rows of grass + 1 row legume, 2 rows legumes + 1 row grass, etc....). Legumes improve fertility and when used as fodder they improve the diet of the livestock (see figure 68).

Planting techniques and management are similar to the ones explained in the above sections. Legumes should also be left wilting and drying for a few days before been given to the livestock.

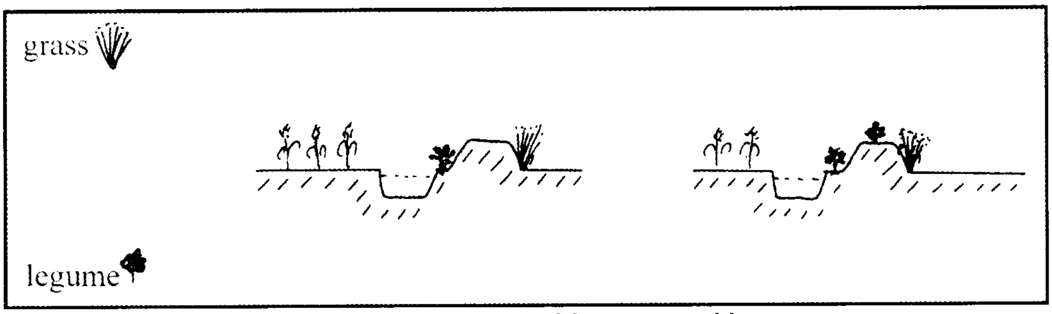


Figure 68 Stabilization with grass and legumes

3. <u>Stabilization with Crops</u>

Traditionally farmers plant different crops along the bunds where moisture is high and sometimes in excess. This practice should be encouraged and improved everywhere (see figure 69).

The **first year**, waterlogging tolerant crops should be planted along the berm such as millet and pigeon pea. Some other crops such as green gram, beans or vegetables (pumpkins, etc.) can be planted on top of the embankment. At the end of the rainy season, the bottom of the collection trench can also be sown with late monsoon crops such as sunflower, chick pea or vegetables.

At **harvesting time** any crop growing on the embankment should be harvested by cutting the stems and not by pulling them out so that the stability of the bund will not be affected.

The second and following years only the space along the bund can be planted with crops (as above). The top of the bund should not be disturbed again but stabilized with grass or trees/shrubs.

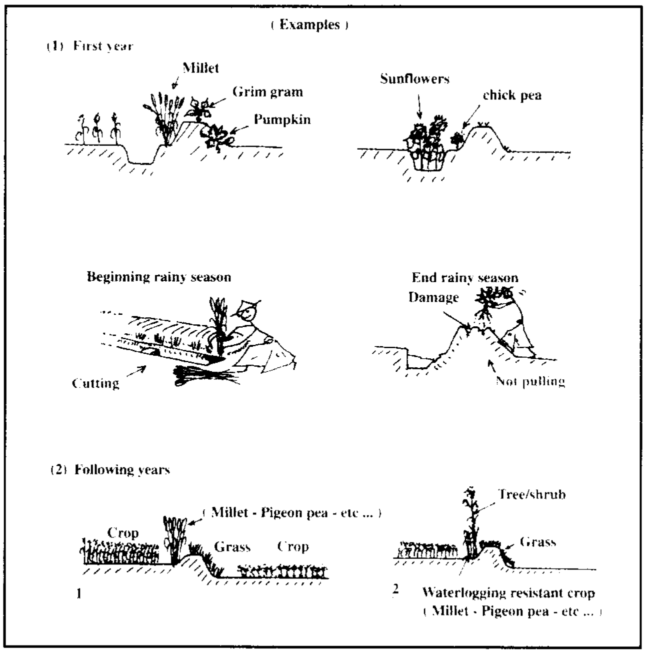


Figure 69 Stabilization with crops

Example of stabilization with a combination of crops (two rows of green gram and pigeon peas on top of the bund + sorghum and maize in the collection ditch + pumpkins on the space between berm and ditch) in Kenbarte - Kyaukpadaung.

4. Stabilization with a Combination of Crops / Grass / Trees / Shrubs

Bunds can be stabilized using a combination of both crops, grass and trees/shrubs, particularly during the first year from bund construction. Later on crops can only grow along the bund and not on the bund itself.

The first year, bunds are i) planted up to the berm with crops, then ii) one or two rows of grass on top of the embankment and iii) trees are planted on the lower side of the bund. Another possibility is to have i) trees planted on the berm at a wider spacing and in between crops are grown, ii) grass are planted at the top of bund and iii) again trees or grass at the lower side of bund (see figure 70). Other combinations are also possible.

For the following years refer to the above sections combinations.

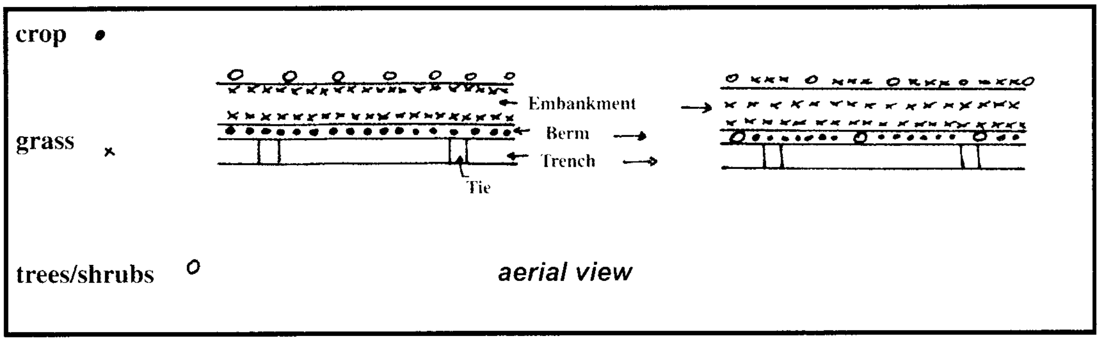


Figure 70 Example of combination of crops/grass/trees/shrubs (first year)

5. Stabilization of SS Dam

SS dams are very important structures which should be stabilized promptly and effectively. Since considerable amount of water is collected by the SS dam for several months, ground moisture levels raise up and valuable trees can grow on both sides of the dam embankment (see figure 71).

Tree species suggested are mostly fruit trees such as Custard Apple, Papaya, Coconut (saline conditions), Mango and Banana. But also Toddy palms and other multipurpose trees such as Acacia Catechu and Neem. Many others are also possible. Planting Bamboo is also suitable for its valuable use (food, netting, construction, fencing, etc.). Grass can also be planted in series of rows on both sides of the earthen part of the dam embankment.

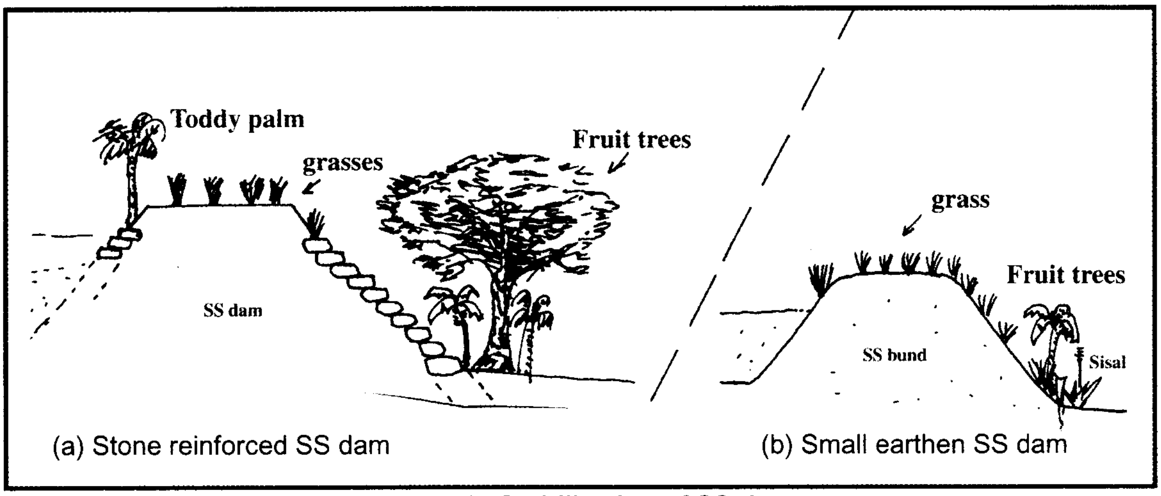


Figure 71 Stabilization of SS dams

6. Stabilization of Check Dams

Similarly to SS dams, the check dams should be stabilized with fruit trees or other multipurpose trees/shrubs. Select the species depending from the type of soil and moisture conditions (figure 72). Checkdams can be also stabilized with improved grasses, bamboo and fiber plants such as Sisal. Farmers may also prefer to grow crops such as millet or vegetables on the residual moisture.

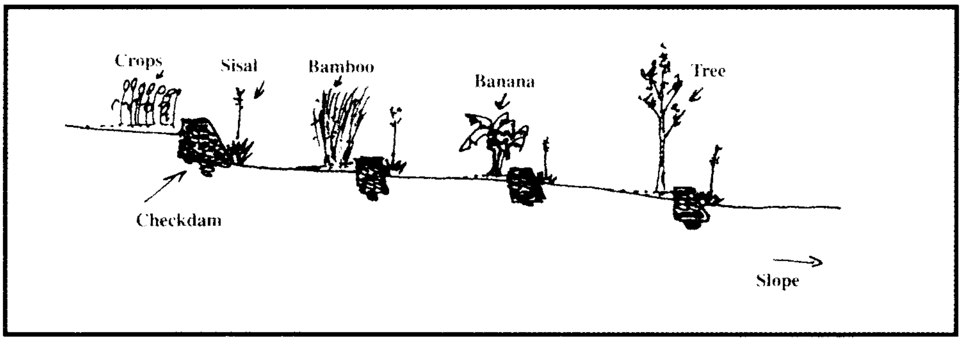


Figure 72 Stabilization of checkdams

SUMMARY OF CHARACTERISTICS OF MULTIPURPOSE PLANT SPECIES

Plant Species	Suitable Soils	Altitude (meters)	Rainfall (mm)	Seed-rate (kg/ha)	Seed Treatment	Tolerance to Drought	Tolerance to Water-logging
(A) Grasses							
1. Cenchrus ciliaris (Buffel)	Light textured well drained soils	Upto 1800	350-1000	3 - 5	Six months rest period after harvest	Very good	Poor
2. Chloris gayana (Rhodes)	Light textured loam soils	Upto 2000	600-1000	4 - 6	No dormancy but seeds improve in storage	Good	Fair
3. Panicum maximum (Guinea)	Well drained medium textured fertile soils	Upto 1900	650-1500	4 - 10	Six months rest period after harvest	Good	Poor
4. Phalaris aquatica (Phalaris)	Heavy fertile soils	Above 2000	430-650	6 - 10	No treatment	Very good	Good
5. Pennisetum clandestinum (Kikuyu)	Heavy fertile soils	Above 1800	1000-1600	3 - 6	No treatment	Fair	Fair
6. Pennisetum purpureum (Napier)	Well drained heavy fertile soils	Upto 2000	800-1000	Cuttings	No treatment	Fair	Poor
7. Setaria anceps (Setaria)	Well drained fertile soils	Upto 2000	500-700	5 - 10	No treatment	Fair	Good
8. Sorghum almum (Columbus)	Black alluvial soils	Upto 1800	400-900	5 - 7	No treatment	Good	Fair
(B) Legumes							
9. Desmodium uncinatum (Silverleaf desmodium)	Well drained sandy loam soils	Upto 2000	900-1000	2 - 4	Seed inoculation	Fair	Fair
10. Lablab purpureus (Lablab)	Deep sandy to clay loam soils	Upto 2000	700-2000	5 - 7	-	Good	Fair
11. Macroptilium atropurpureum (Siratro)	Light textured low fertility soils	Upto 1700	700-800	4 - 4	Seed scarification	Good	Fair

Plant Species	Suitable Soils	Altitude (meters)	Rainfall (mm)	Seed-rate kg/ha)	Seed Treatment	Tolerance to Drought	Tolerance to Water-logging
12. Stylosanthes guianensis (Stylo)	Coarse textured well drained soils	Upto 2000	900-4000	1 - 3	Seed scarification	Good	Fair
13. Stylosanthes hamata (Varano stylo)	Poor scrub soils	Upto 1800	300-1250	3 - 6	Seed scarification	Very good	Poor
(C) Tree Fodder							
14. Acacia albida (Albida)	Deep sandy loam soils	Upto 2000	450-800	Seedlings	Seed scarification	Good	Poor
15. Acacia saligna (Saligna)	Poor rocky soils	Upto 3000	450-800	Seedlings	Seed scarification	Good	Poor
16. Albizia lebbeck (Albizia)	Well drained medium soils	Upto 1800	600-2000	Seedlings	No treatment	Good	Poor
17. Atriplex nummularia (Atriplex)	Poor sandy soils	Upto 1800	150-200	Seedlings or cuttings	No treatment	Very good	Fair
18. Cajanus cajan (Pigeon Peas)	Variety of soils	Upto 1800	600-1000	2 - 6	No treatment	Good	Fair
19. Leucaena leucocephala (Leucaena)	Well drained heavy fertile soils	Upto 1800	500-2000	5 - 10 or seedlings	Seed scarification and Inoculation	Good	Poor
20. Moringa stenopetala (Moringa)	Variety of soils	Upto 1800	500-1100	seedlings	No treatment	Good	Poor
21. Prosopis juliflora (Prosopis)	Sandy or Rocky desert soils	Upto 1600	150-600	Seedlings	Seed scarification	Very good	Poor
22. Sesbania grandiflora (Sesbania)	Heavy well drained soils	Upto 1800	1000-2000	Seedlings	-	Fair	Fair
23. Sesbania aculeata (Sesbania)	Poor scrub soils	Upto 2000	550-1000	Seed or Seedlings	No treatment	Good	Fair

F-.

SOIL AND WATER CONSERVATION MEASURES ON GRAZING LAND

SMALL SOIL OR STONE FACED/SOIL LEVEL BUNDS USING RUNOFF/RUNON AREAS

Definition and scope

The main objective of this measure is to considerably **increase the biomass production of forage grass and legumes pastures and fodder crops** and/or allow the introduction of species having higher water requirements in abandoned, marginal and eroded areas. The principle of the system and its application is the same as for runoff/runon systems suggested for the cultivated areas.

Rainfall multiplier systems for grazing lands are aimed at rehabilitating fertility of depleted soils on gentle slopes, long fallow, crusted and shallow soils and marginal lands used for temporary grazing. In the whole Dry Zone there are a number of areas with these characteristics. For instance many of the eroded hillsides in Magway township have on their top small plateaus which can be treated with rainfall multiplier systems. In Kyaukpadaung and Chaung U townships, a number of marginal lands, left fallow for years, may also be suitable for this measure, in combination with agronomic measures such as ley cropping and other measures such as ripping and bunds. In this respect, a few years pasture improvement and soil fertility restoration may allow the area to be cropped again. Small farmers having difficulties to feed their draught animals may be suitable candidates for this measure and likely interested to take care of the reclaimed areas.

The main difference between this measure and the one described for the cultivated land is that instead of food crops fodder is produced. The system is less demanding in terms of size of structures and management of the cultivated plots.

It should be mentioned that fodder species require less water than food crops. Accordingly, it is possible to introduce this measure in areas where food crops can not grow, even with the support of rainfall multiplier systems.

Technical specifications

The system is suitable for **shallow soils** (<50 cm) and located in marginal areas or adjacent to gullies but with **slopes ranging from 1 to 5%.**

The **minimum area of a plot** should be sufficient to allow the construction of bunds (25-50 m x 15-20 m). If the area include small depressions or gullies, the bunds should wing up before crossing such points. Gullies should be treated with checkdams and revegetated in order to evacuate excess runoff from the tip of the side bunds (see Fig.73). Before the construction of the bunds, the cropped area should preferably be ripped to increase infiltration and encourage biological life.

Concerning the **ratio between runoff area and planted area**, it should be estimated according to the amount of rainfall (mean seasonal). The planted area should not exceed 5-10 meters width. Runoff/runon ratios of 1:1 and 2:1 are suggested for the Dry Zone.

Since the type of soils are usually shallow, with structural problems (crusts, etc.) and limited water storage capacity, excess runoff is expected to occur. For this purpose, bunds should be provided with **lateral wings of decreasing height to evacuate excess water and/or side spillways. The bunds wing up laterally for the entire length of the cropped area.**

Spillway construction follow the same criteria as indicated for soil bunds but often of smaller in size due to the smaller size of bunds. Although slightly increasing costs, on fallow lands intended to be returned to cultivation of food crops the provision of spillways may be justified.

Suggested dimensions are: **height of the bund** is 45-60 cm (1.2-2'), **length** 10-50 meters (32-164') and **width** 1-1.5 meters (3-5'). The bunds have to be staggered alternatively with **lateral spacing** between bunds of 2 meters (6.5') to allow overflow.

The bunds are made out of soil or stone faced. The latter are provided with one stone line apron on the downstream side of the bund. In case of stone bunds, structures should be sealed with soil on their upper side. The **ridging** of the cropped area is possible but normally one-two ploughing operations are sufficient.

The plantation of drought resistant trees and shrubs along the bund is recommended.

The **work norm** is estimated at 45' per person per day.

To restore fertility, **compost application** is recommended. Besides, first year crop residues should be **stubble mulched**. In case of grass/legume pastures, first year reseeding should be allowed and grass cut after they reach maturity. The area should be guarded or allowed to be lightly grazed by animals if cut and carry is too difficult (lack of labour). **A light fertilization** is also recommended ($^1/_2$-1 bag of NPK per acre). For other biological measures refer to the options for cultivated land and adapt them to the pasture land improvement. To improve water holding capacity of the area and encourage fast growth of pasture or fodder crops, **ripping** is recommended (one passage every 3') followed by 1 or 2 ploughing operations.

Main limitations refer to the **labour inputs** available for this activity and the uncertain response of the soil to the new management. Others would be the **control grazing arrangements,** always difficult to maintain in case of marginal areas, particularly if other areas in the surroundings are still grazed freely.

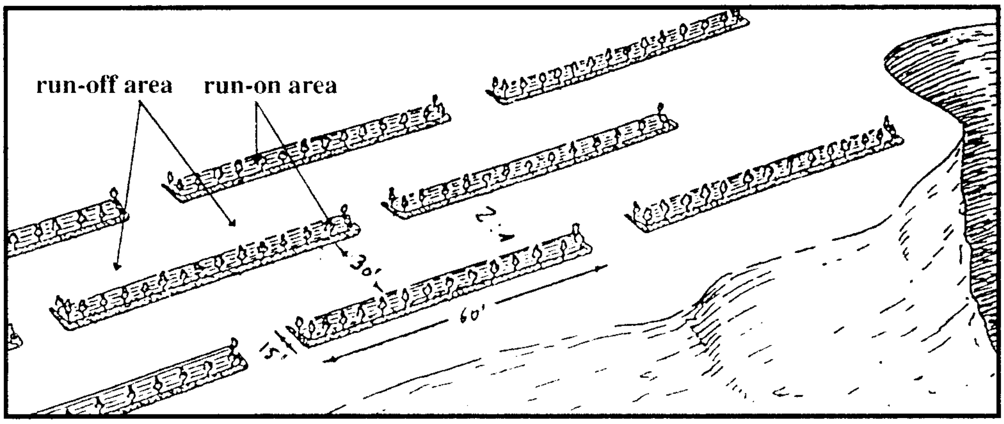


Figure 73 Small stone faced/soil or stone level bunds using run-off/run-on areas

Rainfall multiplier system (staggered position of bunds) in In kyin - Magway

Rainfall multiplier systems (1:1) after rains in Tan Pin Kine - Kyaukpadaung. Beans are grown in the runon area and runoff area is covered with grass. Note the clear difference in terms of biomass production between this field and an untreated area above the gully (upper part).

NARROW STONE LINES (STAGGERED ALTERNATIVELY)

Definition and scope

This measure is less time consuming and less labour intensive and material demanding than the above one. The principles are the same but the measure is applicable only if stones are available. Stone lines are semi-permeable or permeable structures, intended to capture some moisture and thus allow the growth of grass. By slowing down runoff they also decrease erosion, although not completely.

Technical specifications

Layout is along the contour, in successive semi-circular lines staggered alternatively.

Slope should not exceed 3%. The soils should be permeable enough to allow sufficient infiltration although this measure is often implemented in areas with crusted and shallow soils, paved with stones. In this respect, stone lines can be easily overtopped by excess runoff. **It is a cheap method but it is neither an effective erosion control nor an optimal water retention system.** Bunds are easily damaged and maintenance should be frequent.

Stones lines are built with a 20-30 cm **height** and are usually 10-40 meters **long**. Normally, for maximum water retention the two lines are spaced apart 5 to 10 meters.

Grass/legume should be drought resistant and withstand low fertility levels (fertility building pasture or legume crops). Mulching of the area is recommended. Other biological measures can be applied but farmers may not be willing to invest many resources for a low productivity device.

Control grazing and cut and carry are required. Work norm is 40' per person per day/ acre if stones are available within the site and around 60' if they are to be transported from adjacent areas.

Limitations refer to labour availability for continuous maintenance and control grazing.

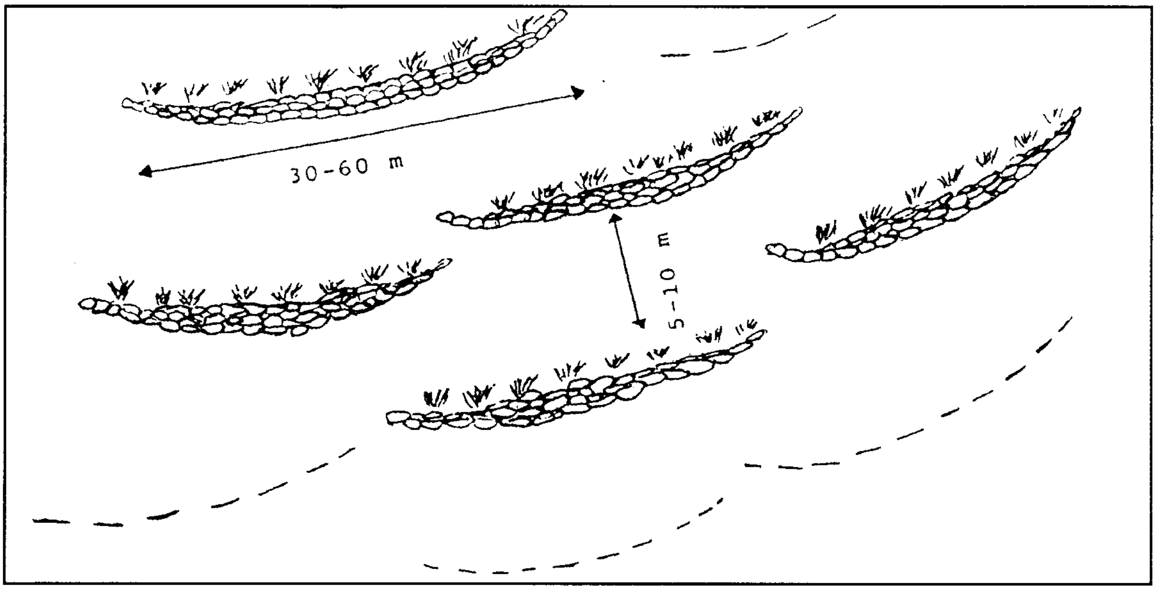
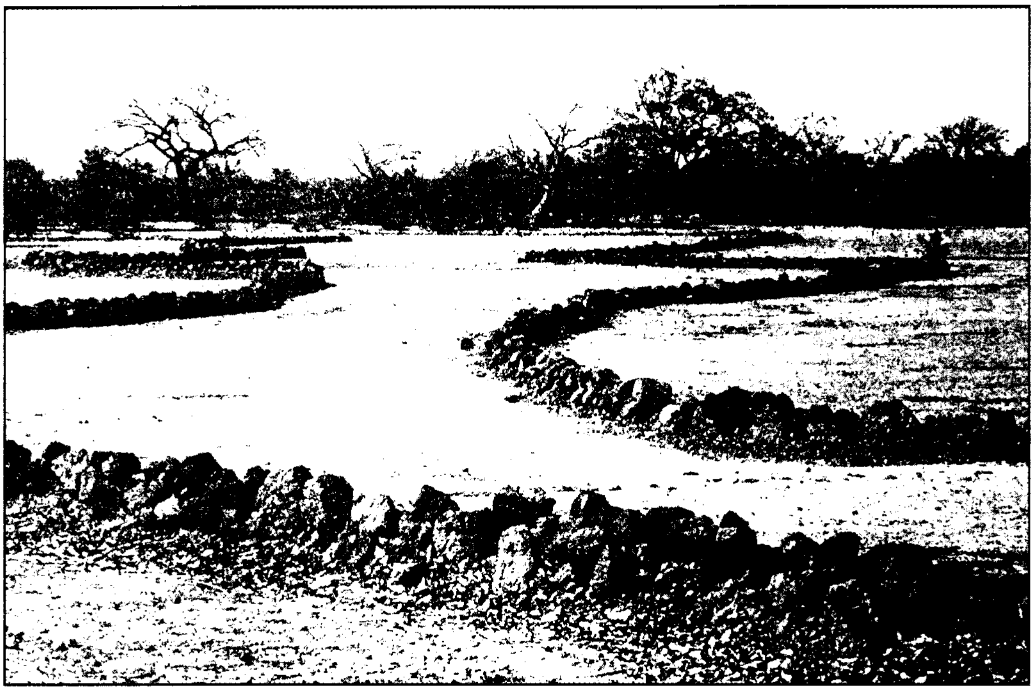


Figure 74 Narrow stone lines staggered alternatively



Stone lines set out on the contour (Burkina Faso)

LARGE HALF-MOON STRUCTURES (STAGGERED ALTERNATIVELY)

Definition and scope

The measure is similar to the one described above, with the difference that it applies to sandy, sandy-loamy soils affected by low fertility levels and thin surface crusts that inhibit infiltration and increase runoff.

Technical specifications

Structures are semi-circular bunds 5-15 meters large, 50-75 cm high and with a decreasing height at their tips to evacuate excess water although soils are often permeable enough. Slopes should not exceed 5% and soil depth should be not less than 50 cm.

Other specifications are similar to the measures described above, including work norms.

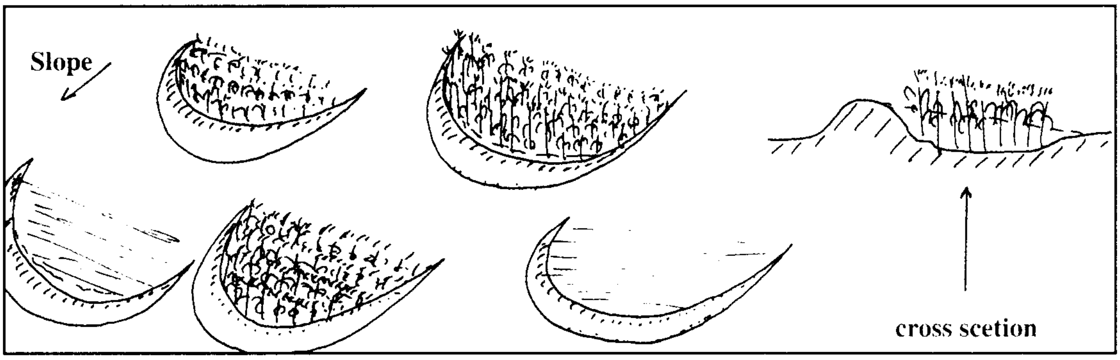


Figure 75 Half-moon structures for forage production

Half-moon basins rehabilitate degraded lands and support a crop of millet (Niger).

AREA CLOSURE

Definition and scope

Area closure a is protection system to improve land with degraded conditions, limited vegetation, low fertility and severe erosion through natural regeneration. No livestock is allowed to graze, and no human interference is tolerated for 3-5 years, until a 80% grass cover is obtained. The utilization of these areas has to be planned and initiated as soon as a satisfactory state of recovery has been reached. Then the area would be used with care as a source of animal feed and selective collection of woody materials by the community.

Once recovered, **an area closure is also a management system whereby the utilization of the closed area has to be planned and initiated together with local communities so that not to fall back into the degraded situation but to get maximum benefits from the rational exploitation of the land** (see figure 76).

Under Myanmar Dry Zone conditions **closed areas should not simply be degraded lands left to regenerate naturally but should be enriched with additional tree planting, grass stabilization and soil and water conservation measures.** Therefore, the closed area can regenerate faster and effectively. In this regard area closure is to be understood as a set of measures aiming to properly establish and manage degraded communal areas (ranges, hillsides, widespread gully lands, etc.) through appropriate soil and water conservation measures, planting of suitable species of trees and grasses and legumes, and effective and careful management of biomass.

After a few years and even after one season (if other measures are applied), a closed area would be able to **supply a considerable amount of animal feed and woody products.**

Area closure is an effective method to control severe erosion and runoff from hilly ranges and degraded areas, therefore contributing to protect downstream cultivated lands and recharge water tables.

Part of the vegetation regenerated can also be used for the preparation of compost.

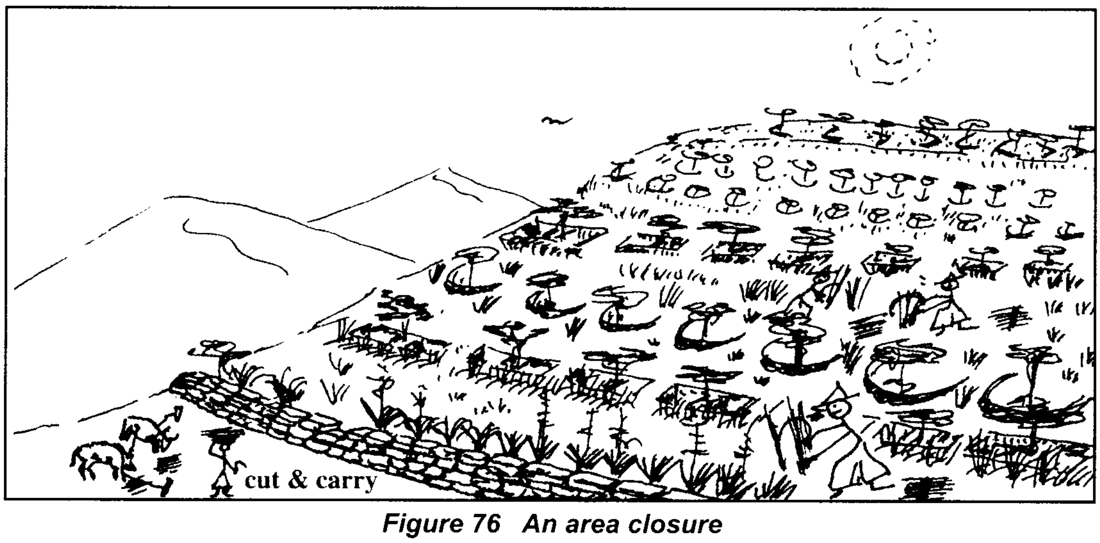


Figure 76 An area closure

Technical specifications

The measure is suitable for any type of soils and slope conditions. In some instances, the access routes to the area are fenced with vegetation.

Establishment and management of a closed area:

(1) Natural Regeneration

Except from not allowing animals to graze no other action is undertaken except some cutting of grass to avoid fire hazards. However, grass should be allowed to seed at least the first year before cutting takes place.

The measure is suitable for any type of soils and slope conditions. In some instances, the access foot paths and cattle routes to the area are fenced with thorny or live fences made out of vegetation. Live fences should be established by using fast growing, drought resistant useful plants (for example sisal, euphorbia, etc.).

Inputs required for implementation are labour for control grazing (agreements, site guards), and eventually fencing.

Cut and carry of grass should take place after one or two years from closure. Some weeding of unsuitable grass species may also occur in order to encourage the growth and dissemination of suitable species only.

(2) Area closure supplemented with plantation of trees, grasses and legumes and soil and water conservation measures.

- **The area is closed but a package of SWC measures is applied contemporaneously.** For instance trenches, microbasins, soil & stone bunds, hillside terraces, planting of multipurpose and conserving trees, and stabilizing structures and slopes with drought resistant and suitable grass/legumes.
- On steep hillsides, in order to reduce erosion, strip planting of forage species along the contours should be followed. Strips of 1.5-2 m wide and spacing apart of 6-8 m should be cultivated along the contours.
- For each of the SWC measures selected to support the growth of trees and the stabilization of structures refer to the other sections of the guideline.

After the first rainy season, cut and mulch grasses after they have seeded (December).

- Plant multipurpose tree species which enrich the soil (nitrogen fixing or high litter producing).
- Starting from the second year, organize the villagers or the interested groups to cut and carry the valuable grass and remove unnecessary vegetation.
- After few years manage the trees by pruning, coppicing and pollarding.
- Make sure that responsibilities, control grazing arrangements (guards, fines, agreements, etc.) and management of the closed area is understood and agreed by the whole community.

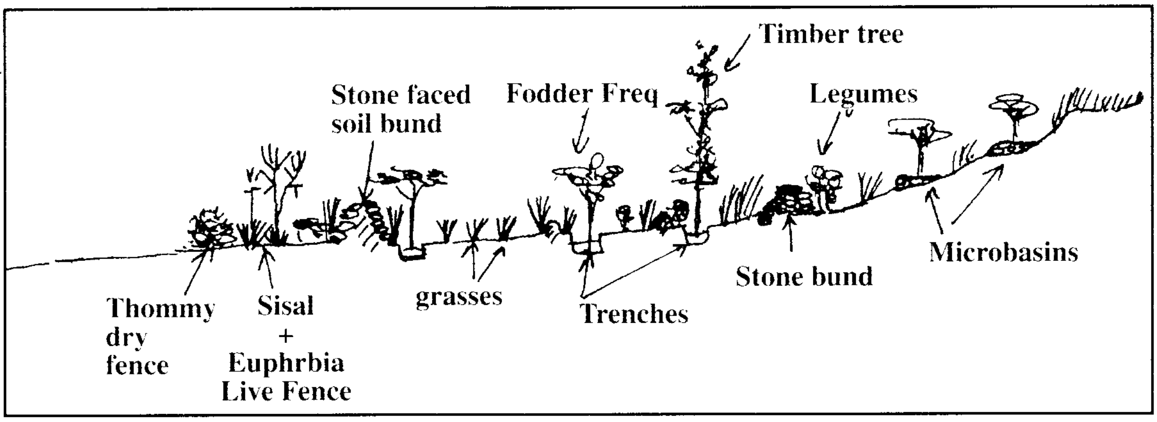


Figure 77 Area closure + SWC + grass & legumes + live fencing

After the period of closure, the area may be converted into a forest or grazing area. In this case apply the specific SWC measures indicated for these two land uses.

Inputs required for implementation are labour for control grazing (site guards), fencing and eventually cut and carry. For additional measures refer to other sections.

The main limitation is the time required to achieve the regeneration and the capacity of villagers to afford not to use the area for a long period of time. However, area closure has been successfully implemented in several parts of the world, often with spectacular results. In the Dry Zone, small degraded areas can be closed and perhaps fenced for demonstration purposes.

The work norm is difficult to estimate. If the area is less than 50 ha one guard would be sufficient.

SOIL AND WATER CONSERVATION MEASURES ON FOREST LAND

COLLECTION TRENCHES

Definition and scope

Trenches are large and deep pits constructed along the contours for the main purpose of collecting and storing rainfall water meant to **support the growth of trees in dry zones (water harvesting effect) and control erosion. The devices are rainfall multiplier systems and allow the collection and storage of all desirable runoff.** They ensure proper catchment protection and rapid growth of trees. By their moisture conservation effect they accelerate the **regeneration of natural and improved grass species** and thus allow the area to supply additional animal feed.

Hillsides treated with trenches ensure the **protection of downstream cultivated areas** and, if limited to only one part of the catchment, control/reduce runoff into gullies and thus facilitate their rehabilitation (see SS dams and gully control measures). Part of the water captured by the trenches soaks into the soil and reach the underground aquifer. Therefore, trenches **contribute to recharge water tables and supply springs and wells with good quality water** and for a longer period of time.

Technical specifications

- Trenches are suitable where **soil depth** is at least 1.5' deep (soil depth refer to workable materials, including soft sandstones) and slope range from 5 to 50% gradient.
- The technique is **designed for maximum water storage capacity** and is applicable in most of the marginal and waste lands (hillsides, gully sides etc.) of the Dry Zone. A site treated with trenches is a zero runoff system, protecting downstream fields from erosion and contributing to the recharge of water tables.
- Trenches are able to accommodate or **harvest around 18-20 cubic feet of water each and are spaced 9-12' apart,** depending from the type of tree species, the planting technique and the nature of the terrain. The **runoff/runon ratio ranges from 4:1 for soils with low infiltration to 5-6:1 for the other soils.**
- In most parts of the Dry Zone, trenches are dug on hillsides having slopes between 5 to 50%, with hard, crusted, low fertility and compacted impoverished loamy clays, sandy loams and sand-clay-loams soils. Their design slightly change depending on the type of soils.
  - For instance, in **loamy clay or sandy clay soils the trench has a tie placed in the middle to impede waterlogging of tree seedlings.** The plantation pit is placed in the middle of the tie.
  - However, **in severe waterlogging prone soils** a higher and larger tie is needed to avoid waterlogging problems (see design for waterlogging prone soils, page 306).
  - **In sandy or sandy loamy soils with low risks of waterlogging, no tie is needed** and the plantation pit is dug in the middle of the trench (see design for sandy soils, page 307).
- Tree species preferred by farmers are **Eucalyptus Camaldulensis and Acacia Catechu. Other species of interest are Acacia Senegal, Cassia Siamea, Leucaena Leucocephala, Azadiracta Indica (Neem), Albizia Lebeck, *etc.***
- Layout start from the top of catchment and proceed laterally and downwards following

the slope directions. An A-frame (constructed based on the size of the trench) is normally used for layout of trenches but a water level is also possible. Every laid out trench is marked with chalk or traced with a hoe.

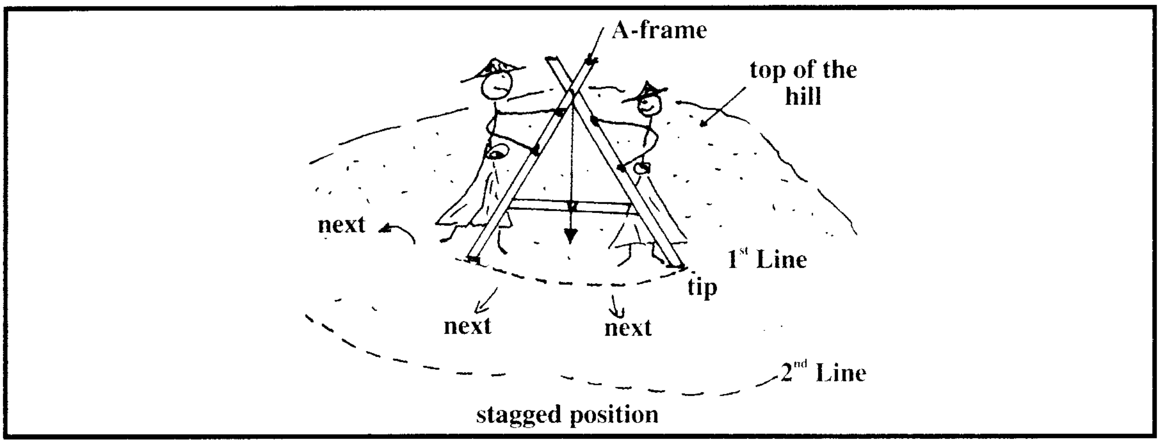


Figure 78 Layout of trenches

Dimensions:

- **Length** 8'-10'(2.5- 3 meters), **width** 1.5' (50 cm) and **depth** (lower side of trench) 1.5' (50 cm). **Lateral spacing** apart two trenches along the contour is 1.5' (50 cm).
- **Trenches should be constructed in a staggered position between subsequent lines.**
- **The tie** should be 1.5-2' wide and 10 inches high from the bottom of the trench if soils do not suffer serious waterlogging (one or few days), 2-2.5' wide and 1-1.2' high if waterlogging is a moderate problem (one week). **The borders of the tie** are placed 6-12 inches from the plantation pit. The size of the **plantation pit** is 1 x1 x1'.

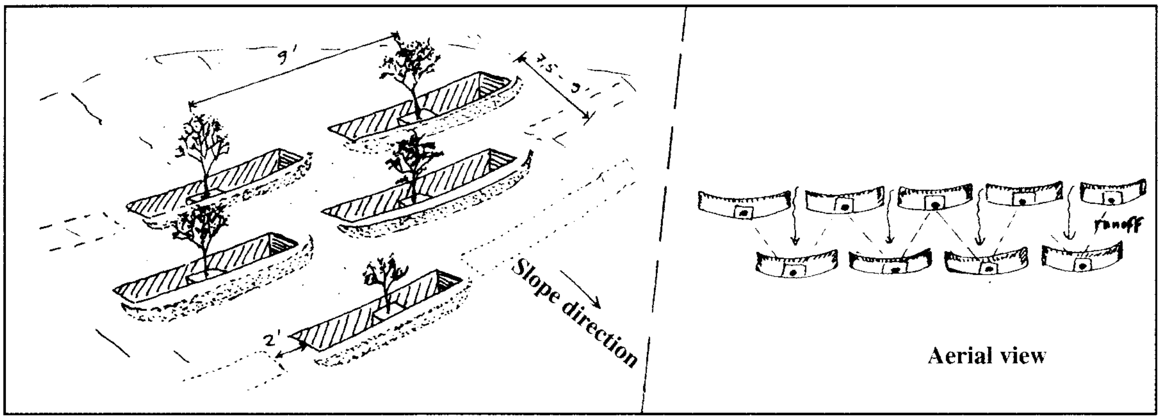


Figure 79 Trenches

Construction phases:

- In normal soils, construction starts by excavating the soil up to reaching 10-15 cm (0.5') depth x 50 cm (1.5') width x 2.5-3 m (7.5-9') length. The excavated top soil is kept aside for filling the pit at plantation time (best soil). A 1 x1 x1' (30cmx30cmx30cm) pit is then dug in the middle of the trench.
- Demarcate the tie around the pit (approx. 0.5' or 10-15cm from the pit on both sides) and proceed to deepen the collection ditches around the ties up to the required depth (1.5' or 50 cm). The piled soil forming the embankment must be shaped level and well compacted.

- **Trenches are slightly curved uphill to follow contours and contrast possible overtopping.** It is very important the bottom of the trench and its embankment are level or slightly inclined towards the tie (2-5% gradient) in well drained soils. The slight inclination allow the concentration of runoff around the tree, particularly in case of light showers.

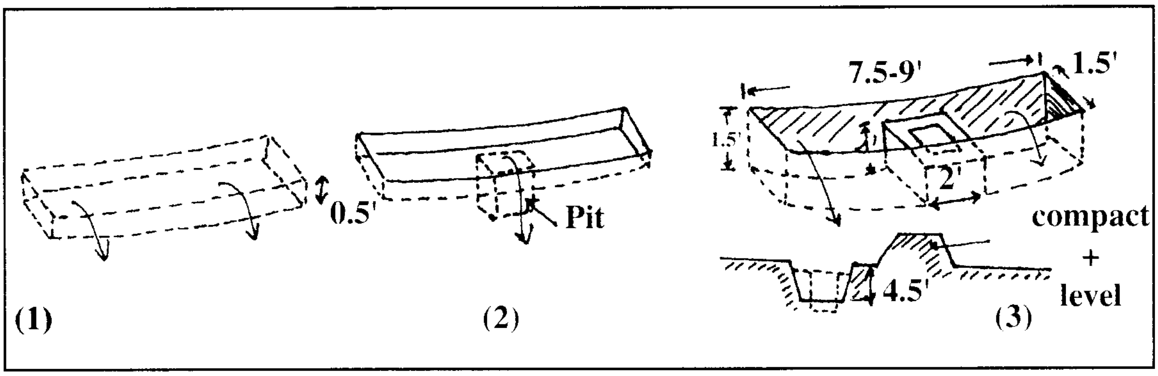


Figure 80 Construction sequence

The work norm for loamy clay hard soils is 3 trenches per person per day (including layout and planting). In sandy loamy soils about 4-5 trenches/day can be constructed. Weeding and mulching requires one person per day/50 trenches. Stabilization requires an average of 1 person/50 trenches/day (including fertilizer application). Manuring or composting of pits requires 1 person/100 trenches/day.

Integration is mainly with stabilization and soil management measures:

- A reforested site treated with trenches should be regarded as a sylvipasture site or even as an agrosylvipasture site where food or forage crops can be grown on the trench embankment (see stabilization of physical structures). Native palatable grass would benefit from the improved moisture conditions and grow well. In this case, seeds should be collected and used the following year to stabilize additional structures. Improved grass/legume pasture species should be also tested in different combinations (see section on stabilization of physical structures).
- **Before plantation, pits should be manured.**
- During the first year, grasses growing in the collection ditches and around the tie should be cut at the end of the rainy season and mulched into the trench to improve fertility and reduce evaporation during the long dry season.
- A light fertilization may be required (NPK) to support the growth of seedlings in very depleted soils.
- **A cutoff drain** may be required above the area treated with trenches if the top portion of the catchment is not included (very steep slopes, rocky, etc.).
- **Control grazing (site guard) and area closure** are often required.
- In very poor soils (sodic, compacted, etc.), the trenches should be planted in the second year, when the biological life and a minimum of soil fertility have been restored (see page 307).

Inputs are labour for construction, planting, stabilization, manuring and mulching. Agriculture tools such as crow bars, pick axes, spades and shovels are required. An A-frame for each group of 20-30 laborers is also necessary.

Management and maintenance: repair of broken structures during heavy storms, gap filling, patching of tree seedlings, de-siltation and improvement of filled trenches, cut and carry, mulching, etc.

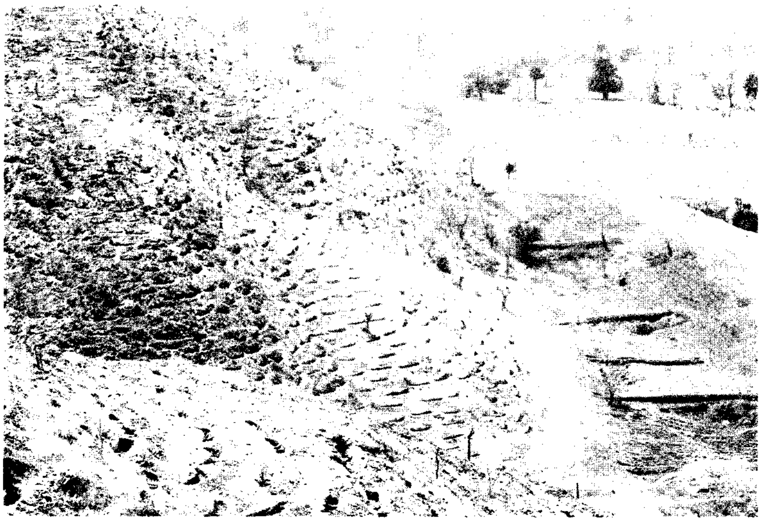
Training is required for layout, construction and management/maintenance operations and group formation/consolidation.

Limitations refer to **availability of labour for construction/establishment and continuous care of the woodlot. Land tenure insecurity and lack of trust from villagers may jeopardize the whole effort.**

Trenches after rains full of water planted with Leucaena Leucocephala in In Kyin village (Magway)

Regeneration of biomass around a trench recently planted with Eucalyptus Camaldulensis on a previously bare hillside in Yar Gyi Taw -Kyaukpadaung

Trenches planted with Acacia Catechu after mulching. Note the stabilization of the trench embankment with green gram legume.



Landscape with trenches before and after the rainy season in Kenbarte village (Kyaukpadaung). Note the vigorous regeneration of grasses and blooming of natural trees/ shrubs

Variations to Original Design

1. Severe Waterlogging Prone Soils

This section refer to soils having serious waterlogging (ponding) problems, in particular those soils where water stagnates in the trench for over a week.

These type of soils are either affected by sodicity and/or have major structural problems such as impermeable subsoil layers, heavy clays, very poor organic matter content, sealing and cracking when wetting and drying. If you have doubts about these characteristics carry out a soil sample analysis. In this case collect a few representative samples and consult the Forestry expert. After the analysis you will know which planting technique and species to adopt. However, in absence of soil lab analysis and whenever the above characteristics are observed, follow the procedures and techniques indicated below which will improve the soil structure as well as the survival rate and growth of trees. In this way it is possible to reclaim critically depleted soils and lands considered lost for agriculture.

Proceed to construct, plant and stabilize the trench:

Year 1

- Dimensions of the trench should be 9' length x 1.5' depth x 1.5' width. Spacing between two consecutive trenches should not exceed 7.5' to avoid excess melted sediments to fill the trench.
- In this case the **tie is placed up to the ground level** and the 1 x1 x1' pit is dug between the tie and the berm (see figure 81).

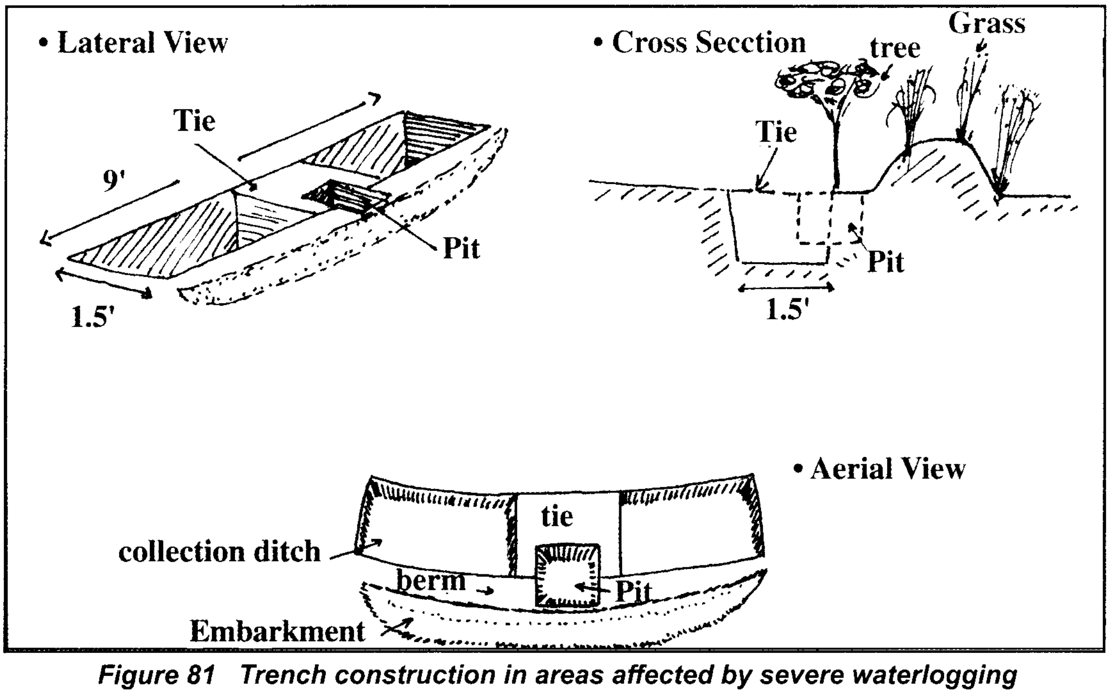


Figure 81 Trench construction in areas affected by severe waterlogging

- It is recommended to **heavily mulch the trench and the pit after construction by bringing roughage and grass from other areas** (lowlands, pastures, field boundaries).
- **One month before the first monsoon apply manure and compost** to the pit and a few spades to the side ditches as well.
- **During the first year rainy season do not plant tree seedlings but try direct sowing**

of Acacia Catechu (which is a waterlogging resistant tree) by throwing a few inoculated seeds into the pit.

- Plant suitable grasses (saline/sodic resistant) on the trench embankment after the first effective rain shower (1st year).
- Let the trench soak with water and fill up with some silt for an entire season.
- After two months from the end of the 1st rainy season (Oct-Nov) **cut and mulch the grasses which have grown inside and around the trenches.**

Year 2

- Before the second year rainy season (May) and only if the first planting attempt by using seeds failed, **excavate the soil from the pit and keep it aside.**
- Select then suitable tree species (Acacia Catechu is recommended) for next planting. Plant the tree seedling and fill the pit with the good soil kept aside. Add some more compost if necessary.
- Carry out **weeding and mulching of grasses** few months after the end of the second year rainy season.
- The area has to be protected from interference (cattle trampling on structures, fire hazards, etc.).

Limitations: **additional costs may be involved (cut and carry of grasses, mulching, manuring, purchasing of extra grasses if necessary) and thus the measure is more expensive.**

Other specifications: see trenches above

Year 1				Year 2		
Nov-March	May	June-Aug	Oct-Nov	May	June-Aug	Oct-Nov
Dig trench + Mulching	Apply compost to pit & trench	Plant grasses+ Ac. Catechu seeds	Cut and mulch grasses	Dig Pit + compost	Plant tree (if seed failed)	Cut and mulch grass

2. Sandy Soils

Sandy soils are those who present a coarse structure and a high percentage of sand (soil remain loose even when wet and do not make an aggregate, > 80% sand). Other sandy soils which contain some silt or clay, aggregate a little (but the ball easily falls apart) and show rapid infiltration should be regarded in this category.

Sandy soils are difficult to handle because of their loose structure. However, they are often a suitable medium to grow trees species with deep tap root systems and allow quick regeneration of grass cover.

Proceed to construct, plant and stabilize the trench:

- In sandy soils, **dig the trench up to the bottom of the desired depth (1.5') and <u>do not</u> make a tie.** Shape of the trench ditch more or less inclined for better stability (see figure 82). The same applies for the embankment (wider).

- Then dig the 1'x1'x1' pit in the middle and at the bottom of the trench.
- Before the rainy season, **stabilize the trench embankment with dry crop residues** such as sesame or dry grass straws on both sides (berm and lower part of embankment) for enhancing stability during the dry season (against wind) and to avoid rapid filling of the trench during intensive rains (sliding of loose soil).
- Before planting the tree apply manure to the pit.
- Plant the tree during the first rainy season **immediately after the first effective rain shower** (the same day or day after). Planting of trees on sandy soils should be a quick operation because of rapid infiltration of water and scarce water holding capacity of such soils.
- Plant 1-2 rows of grasses (embankment only) and 1 row of legumes (on the berm) for **vegetative stabilization.**
- After the rainy season **cut and mulch the grasses and legumes** (Oct-Nov).
- At the beginning of the second year first monsoon, apply some urea or compost to the formerly mulched grasses to complete decomposition.
- Continue cut and mulch of grasses after second year rainy season.
- If termites are likely to be present select termite resistant trees.

Other specifications: see trenches above

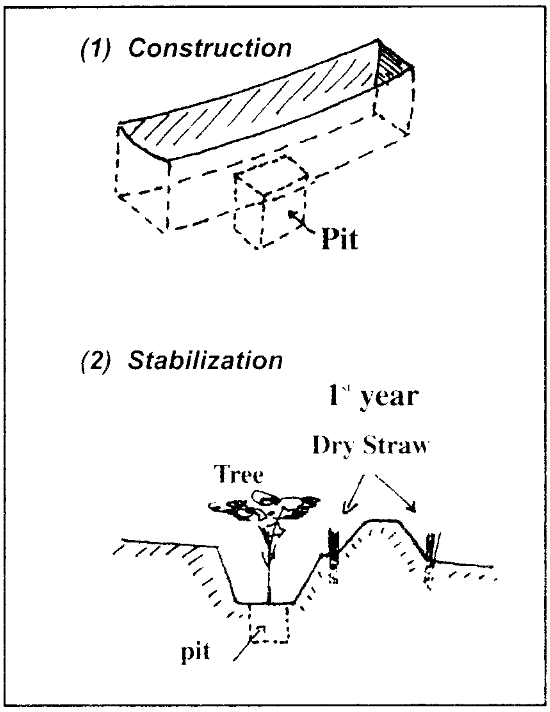


Figure 82 Trench construction in sandy soils

Trench construction in sandy soils + stabilization with sesame crop residues in Té Gyi Kone Village (Magway)

MICROBASINS

Definition and scope

Microbasins are semi-circular structures (micro-catchments) made out of stones and constructed along the contours. They are also named eyebrow terraces. Microbasins are meant for tree planting in shallow and stony soils areas, along gully sides and steep hillsides. Microbasins are rainfall multiplier systems and allow the collection and storage of most of the desirable runoff. They are semi-permeable structures since excess runoff is evacuated laterally or percolate through the upper part of the stone raiser. They ensure sufficient catchment protection and rapid growth of trees. By their moisture conservation effect they accelerate the regeneration of natural grass and thus allow the area to supply additional animal feed.

Other purposes and advantages are similar to those explained for trenches.

Technical specifications

Microbasins can be implemented in gentle to very steep slopes, i.e. 5-100% with soil depth not < 25 cm. Regarding **slopes > 100%,** micro-niches can often be found and spot planting or enrichment plantation can take place.

The **water retention capacity is limited to 6-10 cubic feet** based upon the size of the basin but the measure is effective in very degraded and stony areas. Stoniness should be higher than 25% but round shaped stones should be avoided (not stable).

The structure is semi-circular, made out of stones and sealed with soil on the upper side of the embankment. Microbasins are constructed staggered alternatively. Runoff/ runon ratio is similar to trench.

Dimensions are: 4-6' **diameter**, with a **foundation** of about 0.5'-1' at its lower point and decreasing uphill. The stone riser should be inclined 20% uphill, with the stone lines decreasing height when meeting the upper slope. A 1'x1'x1' ***pit*** is dug near the embankment. **Microbasins may not be able to intercept all runoff** because tree spacing requirements may exceed the diameter of the structure, even if placed in a staggered position.

Microbasin can be designed **with small extended water collection arms (see figure) in order to increase interception.** Eventually, excess runoff is evacuated laterally and do not overtop the structure. For further precaution, an apron line of few stones can be placed at the foot of the structure (downstream). In this respect, a large stone protruding from the foundation can be considered as an apron.

Layout is made using an A-frame, along the contour (same procedure as for trenches).

Construction:

- Construction start by digging a foundation of about 0.5'-1' deep x 1' wide at its lower point and decreasing uphill (1).
- Place large stones in the center of the foundation for maximum stability (2).
- Dig then the 0.5'-1' deep collection ditch and seal very carefully the stone wall with soil (3). The first soil is kept aside for filling the plantation pit. On steep slopes a couple of small pegs will avoid the soil for the plantation pit to slide downwards.

- Then a 1 x1 x1' pit for tree planting is dug in the middle and lower part of the collection ditch (4).

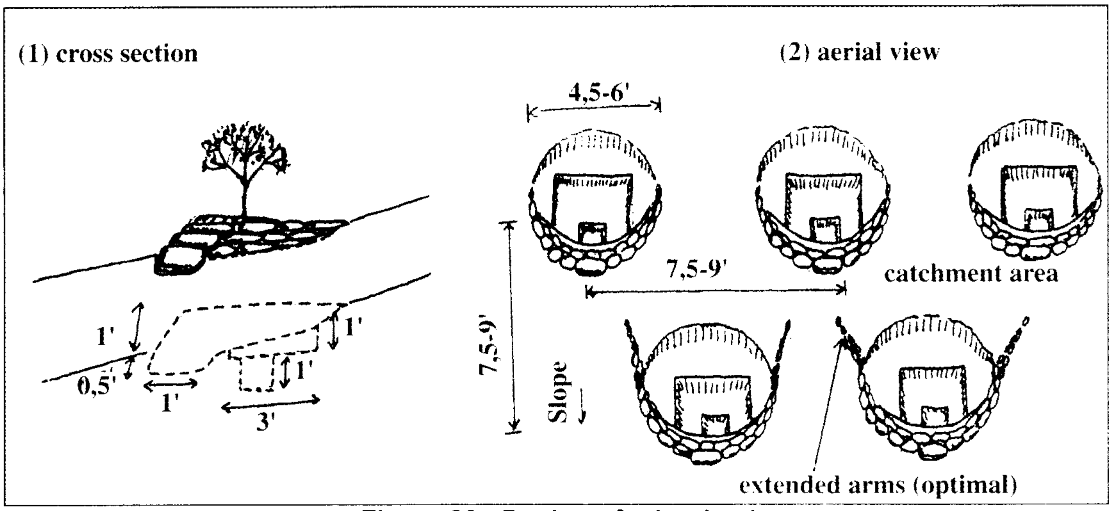


Figure 83 Design of microbasins

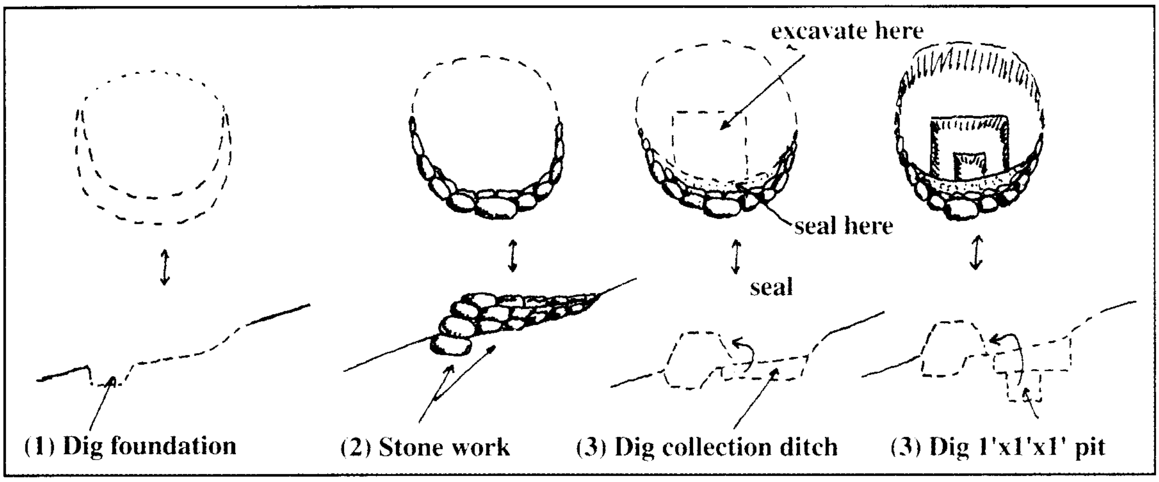


Figure 84 Construction phases

Integration and management:

- Microbasins can also be constructed **in between hillside terraces and stone bunds in slopes ranging from 30-50%**. This is recommended in long slopes, to limit the risk of breakage in case of overtopping of a series of microbasin structures.
- Microbasins **can not be stabilized with forage or food crops** because their embankment is made out of stones. However, as per the water harvesting effect natural grass grow around and inside the microbasin. Other activities such as manuring of pits, mulching of harvested natural grass, control grazing, cutoff drain, area closure, etc. are also possible and recommended (see above for trenches).
- Carry out regular maintenance of the stone structures after rains.

The work norm is estimated of about 5-6 microbasins per person per day (average for a wide range of slopes), including layout.

Limitations and other specifications: same as for trenches

Microbasins under construction on 100% slopes in Kenbarte (Kyaukpadaung)

Hillside treated with microbasins recently mulched

Hillside treated with microbasins on its steeper and upper portion, with trenches on medium slopes and soils bunds on gentle slopes (integrated rehabilitation)

HERRING BONES

Definition and scope

Herring bones are small trapezoidal micro-catchments (named also A-structures) constructed along the contours, meant for tree planting on gentle slopes and different type of soils. Herring bones are rainfall multiplier systems and allow the collection and storage of most if not all required runoff. They are **impermeable** structures since excess runoff is evacuated laterally through the wings. They ensure a good catchment protection and rapid growth of trees. By their moisture conservation effect they accelerate the regeneration of natural and improved grass species and thus allow the area to supply additional animal feed.

Other purposes and advantages are similar to those explained for trenches.

Technical specifications

This technique is suitable for tree planting in most soil type conditions but having **slopes < 5% and soil depth > 40-50 cm** (small plateaus, top of gullies, etc.). These small trapezoidal structures have less water retention capacity (7-12 cub.ft) but are **more economical than trenches within this range of slopes.**

The structures are spaced **9-12' apart**, depending from the type of tree species, the tree planting technique and the nature of the terrain.

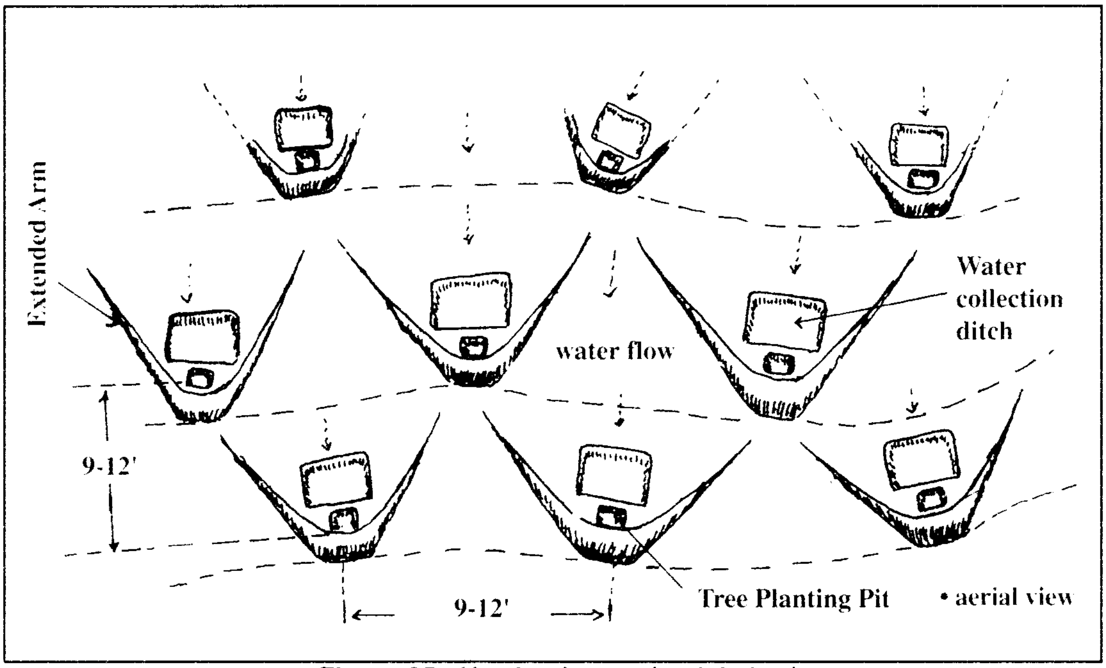


Figure 85 Herring bones (aerial view)

Runoff/runon ratio is similar to trench.

Dimensions:

- The structure is trapezoidal and lateral small bunds or extended water collection arms link one structure to the other, capturing all runoff in between.
- Spacing apart two subsequent lines is 9'-12' and tips of extended arms meet at their end with the tips of the adjacent structure.

- Herring bones (HB) are also placed in a staggered position on the contour.
- HB have a ***collection ditch*** 3'x3'x1' ***deep***. A 1'x1'x1' ***plantation pit*** is dug near the embankment.
- The embankment should be 1-1,5' high, with extended water collection arms of a decreasing height at their tip to eventually allow overflow. The soil embankment should be well compacted and stabilized with grasses.

Layout and construction phases:

- **Layout** starts from the upper part of the gentle sloping land and using an A-frame the same size of the herring bone (9'-12' large) outer tips, level and mark the position of the herring bone.
- Then, rest down to the soil the A-frame and mark the shape of the herring bone by using the shape of the A-frame.
- Continue marking more herring bones with your frame adjacently and below the first one.
- **Construction** starts by digging a 1'x1'x1' tree planting pit.
- Then dig the water collection ditch 3'x3'x1' deep and behind the pit (0.5' tie). Keep some top soil aside for filling the plantation pit. Use the rest to construct the embankment (well shaped and compacted) and the water collection arms.
- The side arms should be well shaped and compacted

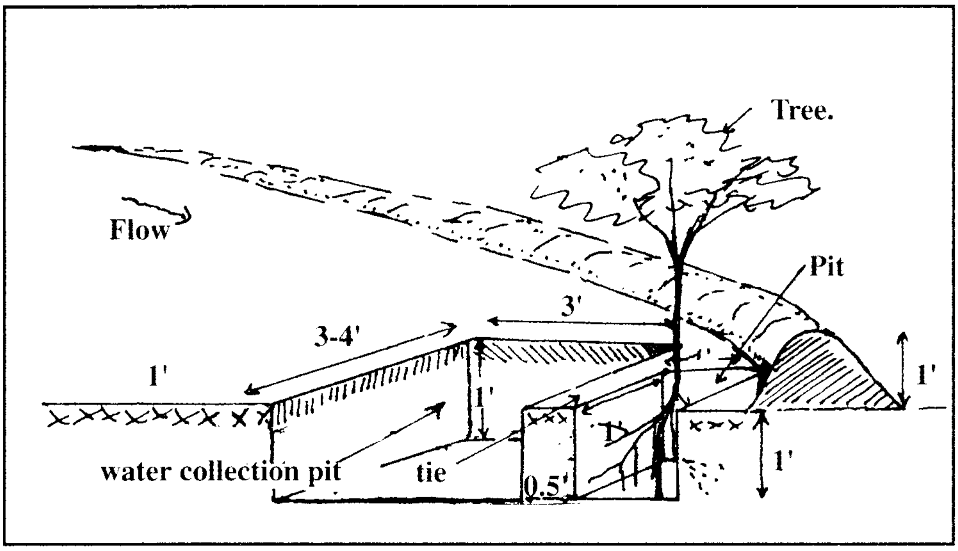


Figure 86 Design and dimensions of H-bones

The work norm is estimated to 5-6 structures per person per day.

HB should be stabilized with forage or food crops for the first year and then after with improved pasture grass or legumes.

Integration and other specifications: as for trenches.

Limitations as specified for trenches. Besides, do not construct HB in sodic soils (waterlogging) or apply same recommendations as for trenches (wider tie, two years cycle, etc.). On sandy soils select trenches or half-moon structures.

The same site after a rain (note the collected water)

Herring bones constructed in In Kyin (Magway)

HALF-MOON STRUCTURES FOR TREE PLANTING

Definition and scope

Half-moon structures (HM) are semi-circular micro-catchments made out of soil, constructed along the contours on gentle slopes where loamy sandy materials accumulate. They are suitable for tree planting and, in some cases, may be effective for growing fruit trees (custard apple, plumps, jojoba etc.) and drought resistant fodder crops (millet, sorghum). For fodder crops refer to the section on SWC measures for the grazing land. Other advantages are similar to the measures mentioned before.

Technical specifications

- HM structures for forestry purposes are suitable for **slopes < 5%** and **soil depth 50-100cm.**
- **Dimensions:** the structures have **4.5'-6' diameter** constructed along the contours and **staggered alternatively.** Structures are **spaced 9-12' apart,** with a soil embankment **1-1.5' high** and **base width 2-3'.**
- **Layout:** same as herring-bones
- **Construction phases:** first the water collection pit is excavated (3'x3'x0.5'), then the soil is piled and compacted 5 inches from the border of the pit, and finally a planting pit 1'x1'x1' is then dug in the lower part of the collection pit. Adjacent structures may be linked laterally by extended water collection arms.
- **Work norm, inputs and other specifications are the same as for herring bones.**

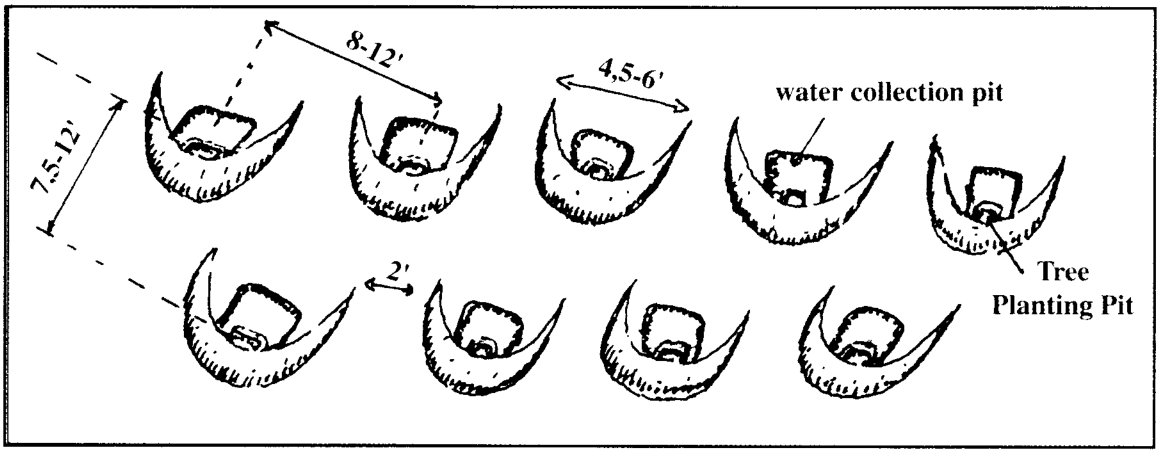


Figure 87 Half moon structures (aerial view)

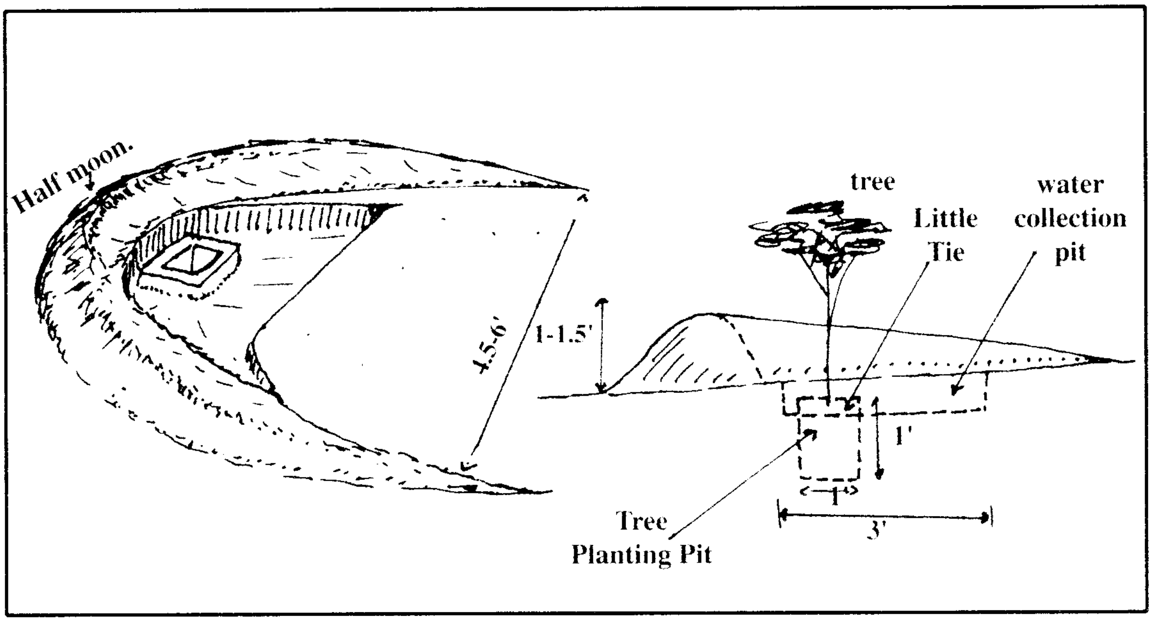


Figure 88 Design and construction

Half-moon structures under construction in Balway (Chaung U)

HILLSIDE TERRACES (LEVEL OR INWARD LOOKING)

Definition and scope

Hillside terraces are physical structures constructed along the contour, generally suitable for steep slopes and shallow soils (although common in other type of soils), suitable for tree planting and rather effective in controlling runoff and erosion. They are popular in several dry zones of the world where they are planted not only with trees but sometimes with perennial crops and fodder species.

Technical specifications

Hillside terraces are either level of inward looking for additional moisture conservation. The second option is more suitable for dry lands. Recommended **slope range** is 30-50% although hillsides are also observed on higher slopes. The workable soil depth should be at least 50 cm to allow the creation of a small platform where to plant the trees. The inward gradient should not exceed 10%. The terrace should be 3' wide (1m) and protected by a stone riser (see figure 89).

The layout along the contours should be very accurate. The **vertical interval** varies from 2 to 5 meters. The terrace is provided with **ties** to avoid eventual lateral movements of water that may occur due to slight design errors during layout. Trees should be planted in **large pits** (at least 30x30x30 cm).

Soils should have a relatively good permeability so that runoff water can be absorbed quickly.

***Construction phases and dimensions* (fig 89).**

- Use the line level or an A-frame for layout. During layout peg the strip where the hillside platform is going to be created.
- Remove the first 10 cm of topsoil and keep it aside for future use.
- Dig a 1' foundation at the lower part of the strip.
- Start construction of the stone wall and fill the space with soil by cutting the slope.
- Raise the wall and continue cutting the slope until you form a small terrace.
- Dig the pit at the desired interval.
- Return the first soil kept aside to the top of the terrace and around the pit.
- Place small ties at regular intervals. Ties should be provided with small spillways.
- If there is a risk that runoff from the catchment area will be greater than the absorption of the cultivated area, outlets at the far end of the terrace side (plus a waterway) should be constructed for evacuation of excess water. In this case the height of the bund at the edge of the terrace should be high enough to avoid overtopping, possible erosion downstream and breakage of structures. Instead, water should discharge laterally, through a system of ties and small spillways. The water should discharge into a natural or artificial waterway (the outlet should be half the height of the bund) by the means of a drop structure (see cutoff drain).

Work norms and inputs requirements: This measure is labour intensive and time consuming. Around 150 person days per km of hillsides based on the proposed range of slope is tentatively estimated.

Integration requirements, management, maintenance, training and limitations: same as for soil, stone faced/soil bunds with runoff/runon areas and bench terrace construction.

Others recommendations such as control grazing, area closure, mulching, etc. are similar to the other measures for forest land.

Modifications to the original design

Double Slope Hillside Terraces

- They are recommended for maximum water harvesting capacity and growth of trees with high water requirements. They may be appropriate **for fruit trees**. They are suitable for **slopes not higher than 50% and soil depth of at least 75-100 cm.**
- Vertical interval and spacing as above.
- The terrace should look backslope first and have a gentle gradient along the terrace of about 0.4-0.5% maximum, interrupted every 1.5-3 meters by a well built stone tie provided with a small spillway (fig 90). The spillways will evacuate excess runoff laterally into a natural or artificial waterway.
- The **layout and construction** of this type of terrace should be **extremely accurate**.
- A water **collection ditch** 6 inches deep is placed before the tie. A **large pit** (40x40x40 cm) is normally dug at the bottom of the tie where water concentrates. To avoid possible waterlogging problems, the pit may be placed at a higher position.
- A waterway construction may be required at the end of the terrace (linked with appropriate drop structure).
- The **work norm** increases up to 250 persons per km of hillsides, including layout.
- The measure, though effective, require continuous management and maintenance, and thus is **justified only for highly valued tree crops.** It requires also qualified expertise to follow-up on the layout, construction and soil/vegetation management aspects (weeding, mulching, etc.). It is recommended to initiate field trials and explore its convenience for highly value trees (Tanaka, fruit trees, etc.).

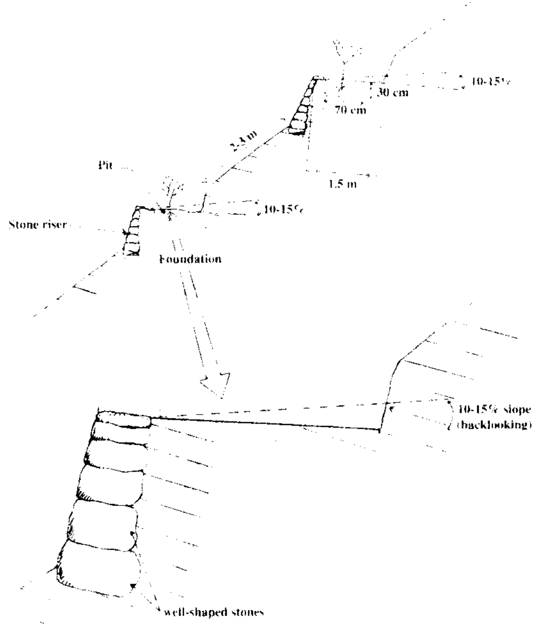


Figure 89 Hillside terraces (inward looking)

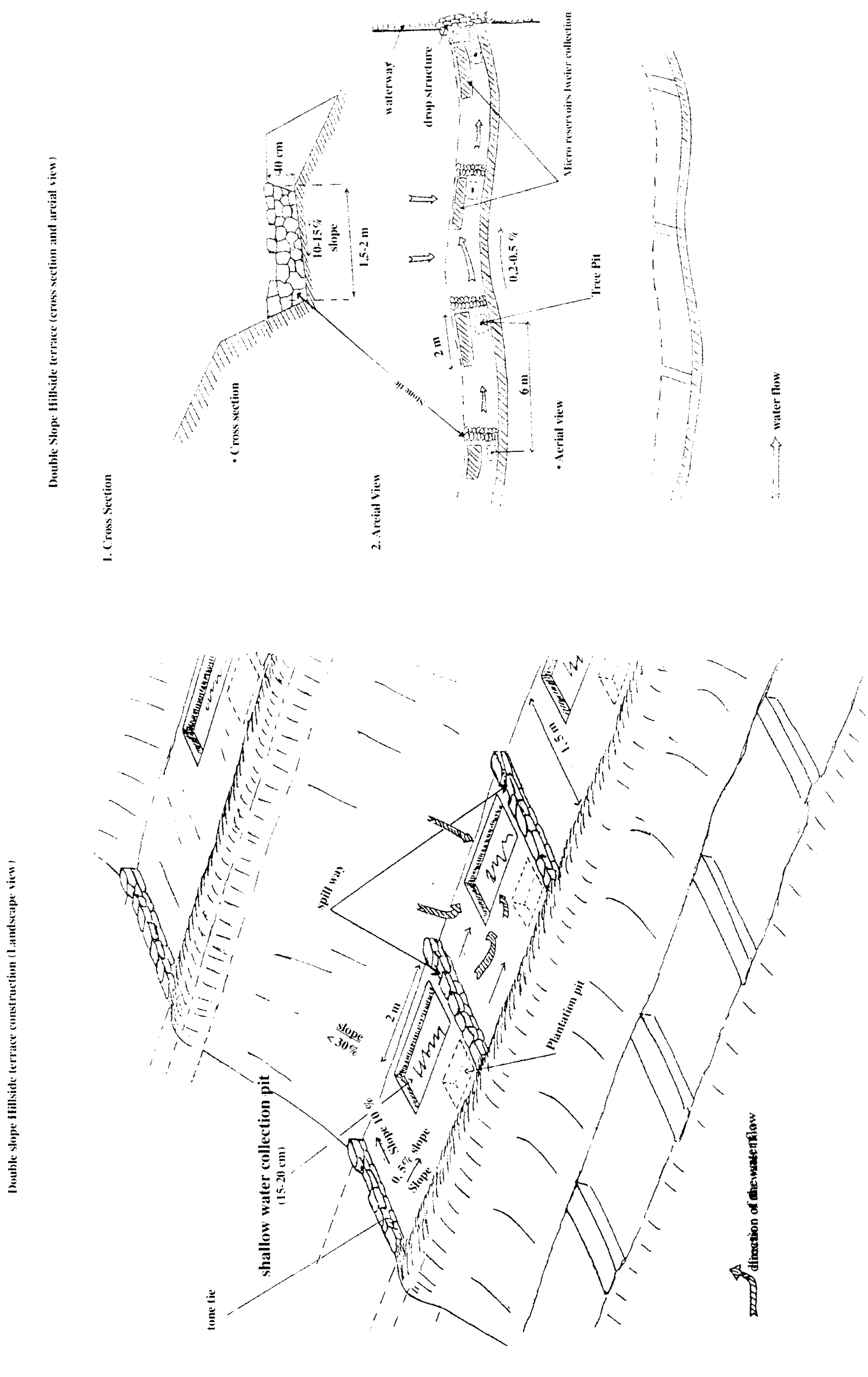
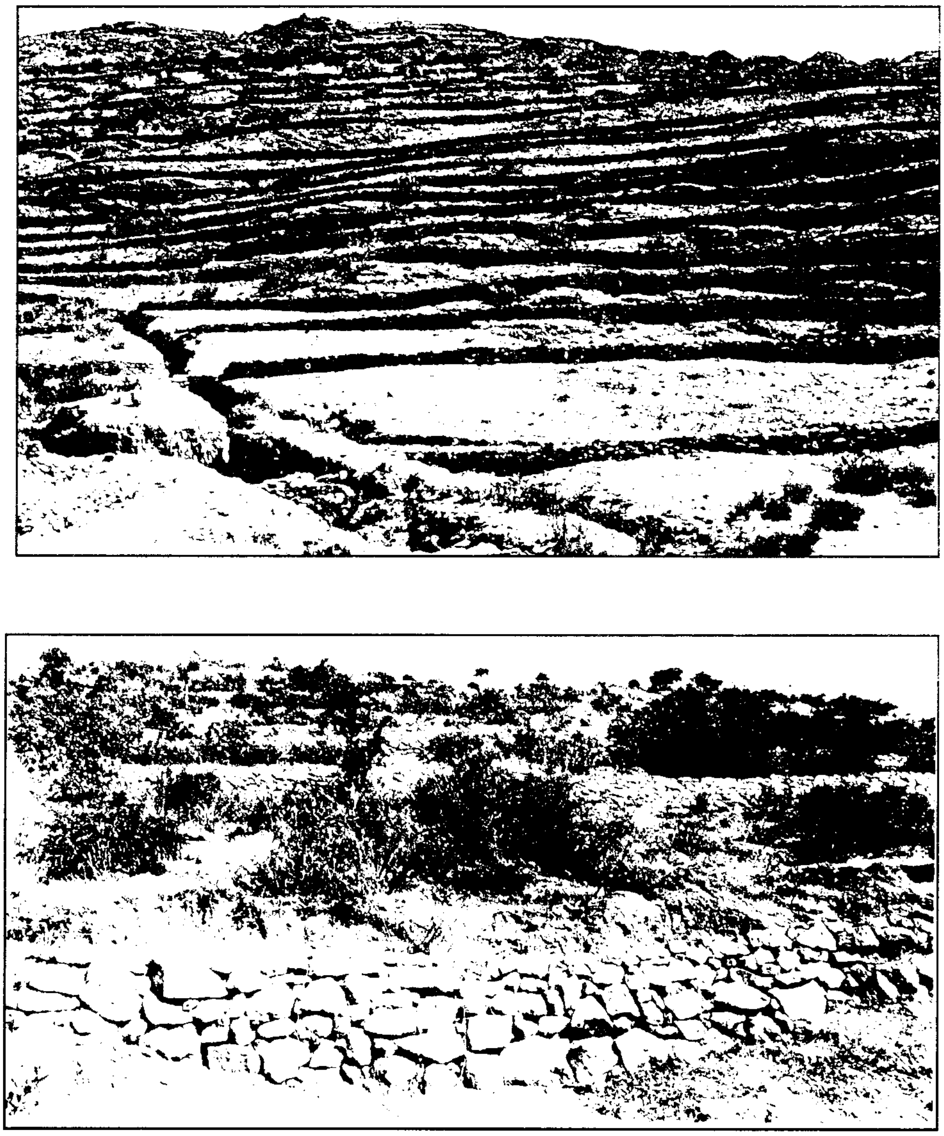


Figure 90 Double slope hillside terraces



Example of Hillside terraces (Ethiopia) in degraded landscapes

IMPROVED PITS

Definition and scope

The pitting method for tree planting is cheap and may be rather effective in relatively good soils and gentle slopes. In the Dry Zone, pitting should not be performed using the grid method that is more suitable for higher rainfall areas and deep soils. In the Dry Zone, **improved pits refer to excavations along the contour and staggered alternatively for maximum water harvesting and retention.** Though the water harvesting capacity of the pit is limited and all runoff may not be checked, the measure is suitable for dense plantations of species such as Acacia Catechyu and Leucaena Leucocephala.

Technical specifications

Pits should be dug in areas with slopes **< 30% and soils with depth >75 cm.** On steeper slopes the small soil embankment would slide downwards and fill the next trench. Pits are made by a **collection pit and a plantation pit dug in the middle and bottom of it.**

Dimensions: the collection pit should have 4-5' length, depth 1.5' and width 1.5'. The plantation pit is 1'x1'x1'. The pits should be staggered alternatively, distance apart should be 6' vertically and lateral spacing between pits 2'.

The ***work norm*** is estimated to 8 pits per person per day.

Integration is with lines of stone faced/soil bunds or stone bunds placed every 3-4 lines of pits. In other instance, instead of the collection trench and ties along the bunds, the same type of pits may be excavated along the bund and soil from the pits used for the bund construction (bund and pit system for tree planting).

Limitations: not appropriate for soils prone to waterlogging. Water harvesting capacity is limited.

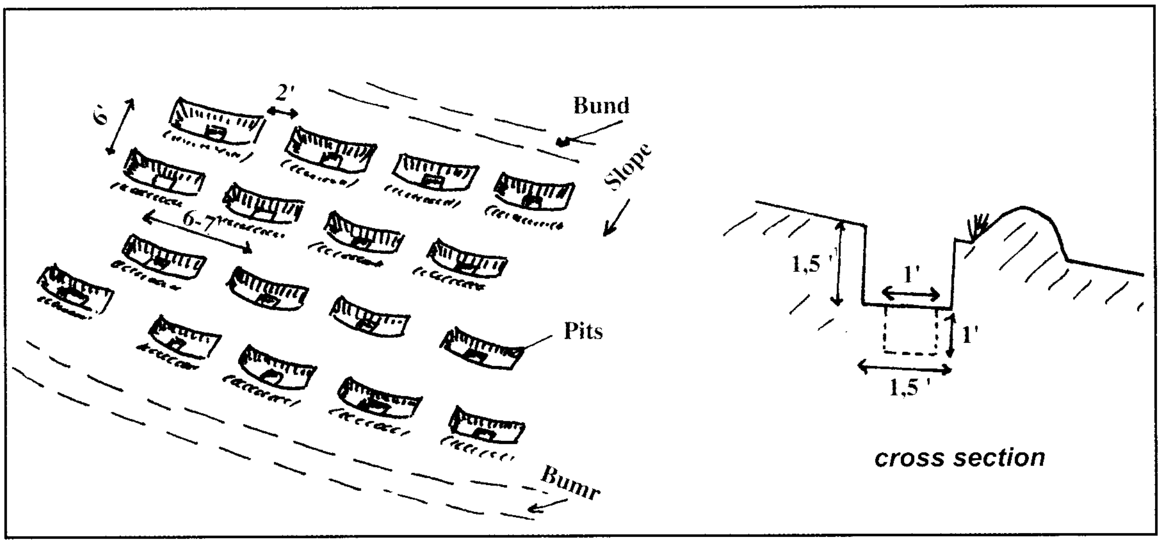


Figure 91 Pits along the contour

WINDBREAKS AND SHELTERBELTS

In arid zones, the harsh conditions of climate and the shortage of water are intensified by strong winds. Living conditions and agricultural production can often be improved by planting trees and shrubs in protective windbreaks and shelterbelts which reduce wind velocity and provide shade. Windbreaks and shelterbelts, which are considered synonymous, are barriers of trees or shrubs that are planted to reduce wind velocities and, as a result, reduce evapotranspiration and prevent wind erosion; they frequently provide direct benefits to agricultural crops, resulting in higher yields, and provide shelter to livestock, grazing lands, and farms.

A main objective of windbreaks and shelterbelts is to protect the agricultural crops from physical damage by wind. Other benefits include:

- Preventing, or at least reducing, wind erosion;
- Reducing evaporation from the soil;
- Reducing transpiration from plants;
- Moderating extreme temperatures.

Quite often, protection can be combined with production by choosing trees and shrub species that, apart from furnishing the desired sheltering effect, yield needed wood and other products.

(i) Design of windbreaks and shelterbelts

- When considering windbreak or shelterbelt planting, three zones can be recognized: the windward zone (from which the wind blows); the leeward zone (on the side where the wind passes); and the protected zone (that in which the effect of the windbreak or shelterbelt is felt).

- The effectiveness of the windbreak is influenced by its permeability. If it is dense, like a solid wall, the airflow will pass over the top of it and cause turbulence on the leeward side due to the lower pressure on that side; this gives a comparatively limited zone of effective shelter on the leeward side compared to the zone that a moderately permeable shelter creates.

- Optimum permeability is 40 to 50 percent of open space, corresponding to a density of 50 to 60 percent in vegetation. Gaps in the barriers should be avoided.

- Permeability of dense shelterbelt can be improved by pruning lower branches at 0.5-0.8 m from the soil level.

- It is generally accepted that a windbreak or shelterbelt protects an area over a distance up to its own height on the windward side and up to 20 times its height on the leeward side, depending on the strength of the wind (see figure 100). In reducing wind speeds, narrow barriers can be as effective as wide ones. Furthermore, a narrow shelterbelt has the advantage of occupying less land.

- The shape of the cross-section of a windbreak determines, to a great extent, the sheltering effect.

- To a large extent, the choice of tree or shrub species to plant, along with their planting arrangement, dictates the cross-sectional shape. In general, an inclined slope facing the wind should be avoided, as it only deflects the wind flow upward. Barriers with a clear vertical side provide best windspeed reduction.

- When designing a windbreak or shelterbelt, the direction of the wind must be considered. A barrier should be established perpendicular to the direction of the prevailing wind for maximum effect. To protect large areas, a number of separate barriers can be created as parts of an overall system. When the prevailing winds are mainly in one direction, a series of parallel shelterbelts perpendicular to that direction should be established; a checkerboard pattern is required when the winds originate from different directions. Before establishing windbreaks or shelter-belts, it is important to make a thorough study of the local winds and to plot on a map the direction and strength of the winds.

(ii) Selection of tree and shrub species

In the selection of tree or shrub species for windbreaks or shelterbelts, the following characteristics should be sought:

⇒ Rapid growth, straight stems, wind firmness, good crown formation, deep root system which does not spread into nearby fields, resistance to drought and desired phenological characteristics (leaves all year long or absent only part of the year).

⇒ Some possible trees and shrubs for windbreaks are: Acacia species (Nilotica, Senegal, etc.), Eucalyptus Camaldulensis, Azadiracta Indica, Leucaena Leucocephala, Zizyphus Spinachristi and Mauritiana.

(iii) Planting techniques

Planting techniques for windbreaks and shelterbelts are identical to those in other tree and shrub planting programmes. However, as windbreaks and shelterbelts require a high plant survival rate, as well as uniform and rapid growth, supplementary irrigation may be required during the establishment stage. Gaps cannot be tolerated and, when plants are lost, replacement must be prompt.

Although in theory, one-row barriers should suffice, experience has shown that the most effective windbreaks and shelterbelts are those consisting of several rows of trees. Quite often, initial spacing is 3 meters between the rows, with trees 2 meters apart in the row. Where trees or shrubs have long roots that could extend into agricultural fields, vertical root pruning may be recommended; this can be done with special equipment or by digging trenches. A triangular arrangement (staggered position between lines) of plants is frequently prescribed.

(iv) Management practices

Once established, the effectiveness and longevity of a windbreak or shelterbelt depends on its maintenance. As the trees and shrubs mature, they change in shape and appearance, which necessitates some level of maintenance to ensure a continuing shelter effect. Pruning may be required to stimulate height growth, while thinning can boost diameter growth.

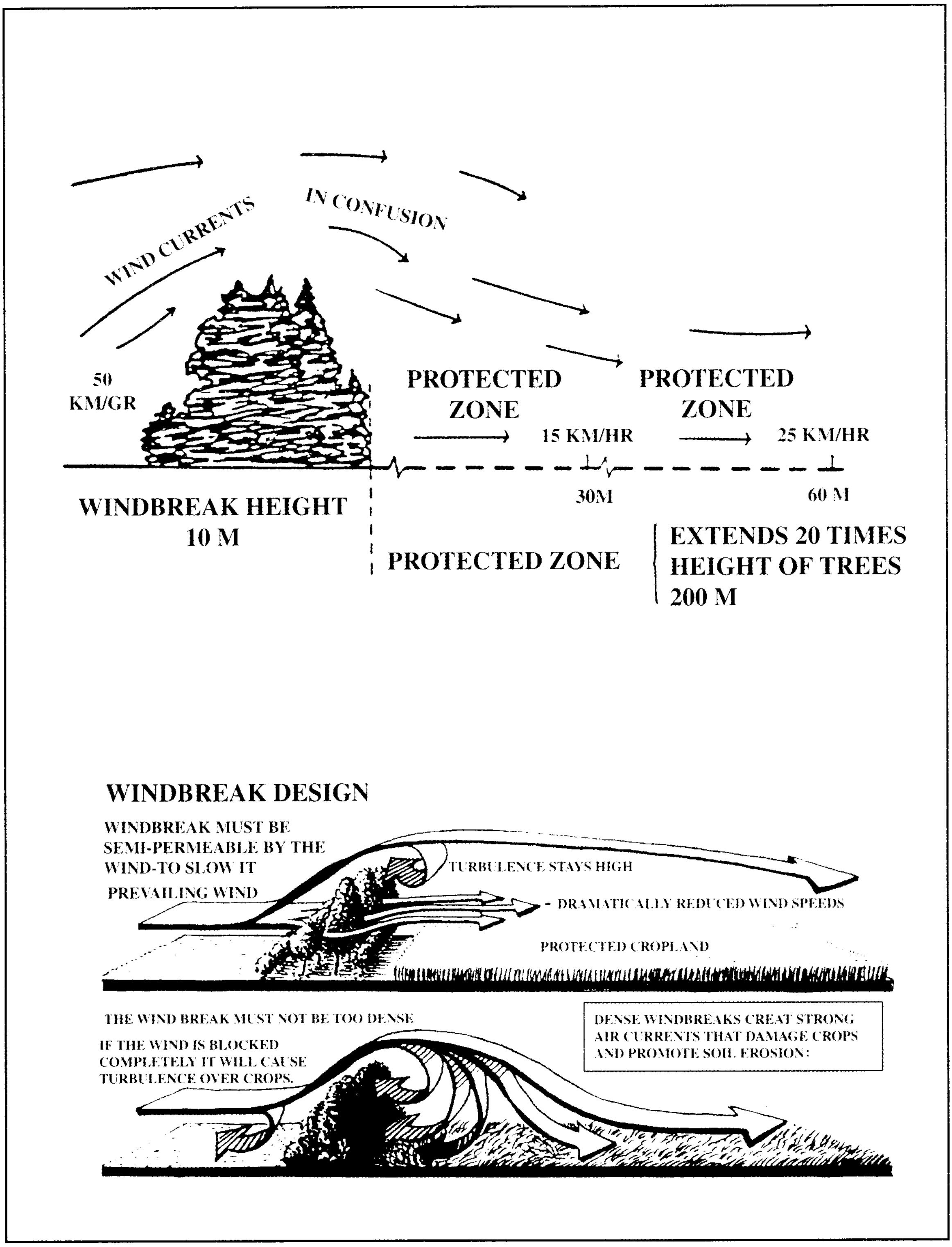


Figure 92 Windbreaks

AGROFORESTRY

This section will briefly highlight the nature and objectives of agroforestry measures and the principal techniques most commonly used in several parts of the world's semi-arid areas.

1. What is Agroforestry?

Agroforestry is a land use system which enables the production of trees, crops, and livestock on a given unit of land either in spatial arrangement or over time to maximize productivity and sustainability of the land.

2. Why Agroforestry is needed?

With farming systems in which trees are not replaced in the same numbers as they are being cut results in that families usually lose easy access to required tree products. Poles and timbers must either be bought or cut from places outside the village. Women and children must walk farther and farther to find an adequate supply of fuelwood, or materials that should be used as natural fertilizers (pigeon peas residues, dried manure, etc.) must be used to supply energy for cooking.

Agroforestry is a land use system that can be used by the rural populations to provide many of their needs. Tree/shrubs planted within and around the fields are a ready and constant source of wood products such as timbers, poles, and fuelwood.

3. List of possible Agroforestry Practices (Adopted from Young, 1986)

(i) **Mainly Agrosylvicultural** (Trees, forage and food crops)

- Planted tree fallow
- Improved tree fallow
- Taungya
- Trees on cropland
- Plantation crop combination
- Tree gardens
- Alley cropping
- Boundary planting
- Trees for soil conservation
- Windbreaks and shelterbelts

(ii) **Mainly or partly Sylvopastoral** (Trees with pastures and livestock)

- Trees on rangeland or pastures
- Plantation crops with pastures
- Live fences
- Fodder banks
- Tree component predominant
- Woodlots with multipurpose management

(iii) **Other practices and special aspects**

- Apiculture with forestry
- Aquaforestry (trees with fisheries)

- Trees in water management
- Irrigated agroforestry

4. *Classifications of Agroforestry Systems:*

There are three major or basic classifications of agroforestry land-use systems:

(a) Trees grown in association with crops (Agri-silviculture)
(b) Trees grown in association with livestock (silvipasture)
(c) Trees grown in association with both crops and livestock (Agri-silvipasture)

5. *What species are ideal for Agroforestry?*

Not all trees/shrubs can be used in agroforestry systems. As a general rule, a good agroforestry species should have several of the following characteristics:

- Multipurpose: e.g. fuelwood, fodder, poles, timber, green manure, etc.
- Fast growing.
- Deep rooted, and narrow root zone.
- Few negative effects on crops (non-competitive).
- Coppicing (the ability to grow back after cutting).
- Nutritious and palatable leaves for livestock feed.
- Nitrogen fixing.
- Produce economic products and by-products which can be used or sold (fruits, poles, etc.)
- Light canopy to allow sunlight penetration.

In general, such characteristics accompanied by good management, provide a positive interaction between the trees/shrubs and their associated food crops and livestock. The specific desired effects will depend upon the wants and needs of the individual farmer.

6. *How Crops Benefit from Trees with Intercropping?*

Nutrients are added to the soil by trees in several ways:

- ***Nitrogen fixation***: Micro-organisms (bacteria or fungi) in root nodules of trees/shrubs fix nitrogen into a form that crops can use.
- ***Green leaf manure:*** Leaf litter from trees provide nutrients and organic matter for the soil. When the leaves fall from the trees or cut and incorporated, they decompose and release humus and minerals to the soil. In a process called "Nutrient Pumping", roots of trees carry valuable minerals from deep below the soil surface, often below the root zone of the agricultural crops to the leaves, and thus eventually back to the food crops rooting zone of the soil.
- ***Root Decomposition:*** Regular coppicing of the trees causes a portion of roots of trees to die back. As they decompose, they add organic matter to the soil.
- ***Conserving Water:*** Trees increase soil-water retention.
- ***Organic matter:*** Like a sponge, organic matter added to the soil by the trees (leaf litter, roots) increases the soil's ability to absorb and retain water.
- ***Windbreaks:*** Between and during cropping seasons, trees act as windbreaks, reducing the rates of evaporation caused by high and dry winds.
- ***Shade:*** Also between cropping seasons, tree crowns shade the bare soil, thus lowering surface evaporation losses. Of course, the wrong trees (especially those with spreading

and shallow and roots) can also deplete soil moisture, and thus harm shallow rooted annual crops near by.

- ***Conserving Soil.*** Trees reduce the rate of soil erosion in many ways:
  - Tree roots hold the soil together. This is especially valuable when trees are planted along the contours of a hillside.
  - Leaf litter on the soil surface, as well as the protection by the tree crown, lessen the force with which raindrops strike the soil. This results in larger amounts of water can soak into the ground; less soil is carried away by runoff; windbreak provided by the trees reduces the wind speed across the crop field, thus lowering the amount of soil blown away and moisture removed; trees/shrubs planted in hedges along contours act as physical structure and thus reduce soil and water erosion.
- ***Weed Reduction.*** As the tree crowns are allowed to grow between cropping seasons, the shade from the crowns suppresses weed growth. The absence of fallow in an agroforestry system prevents a build-up of weed population and the tree hedgerows act as blocks against weed seeds being blown into the crop field.

7. How Trees Benefit from Intercropping with Crops?

Trees seedlings planted with crops have high survival and growth rates because they receive the same attention which is given to the crops.

- They are fenced and/or watched, thus protected from grazing livestock and wild animals.
- They are weeded along with the crops.
- They make use of fertilizers that move below the level of crop roots.

At first, crops such as maize, cassava, sunflower act as windbreaks and nurse crop for the tree seedlings or young trees.

8. How Livestock Benefit from Agroforestry?

Many agroforestry tree species supply nutritious, often protein-rich fodder for livestock (for example: *Acacia albida, Calliandra calothyrsus, Leucaena leucocephala, Prosopis spp.*). Small scale farmers with few livestock can use the leaves, twigs, and pods of these agroforestry species to increase outputs from their animals. During dry periods, when feed for livestock is scarce, trees continue to produce fodder. A farmer who has a continuous supply of nutritious fodder will have healthier animals year-round than a farmer whose animals are well-fed only during the rainy season.

There are two methods for providing livestock with fodder from intercropped agroforestry species:

- "cut and carry"; the fodder from the trees/shrubs is harvested and brought to the livestock.
- letting the livestock graze on the trees/shrubs after harvesting the crops. Weeds and tree/shrub wildings are controlled by the browse, and the manure of the livestock help increase soil fertility.

9. Establishment and Basic Management Techniques

(a) Establishment of the Trees/Shrubs

There are three methods of tree establishment

- Direct sowing of seeds.

- Establishment with seedlings.
- Establishment with cuttings.

The technique suitable for the Dry Zone is planting with seedlings. Seedlings have an advantage over direct sowing of seeds due to the care they receive in the nursery. Their production is more labour-intensive than direct seeding, but have higher initial growth rates in the field, especially in marginal lands.

(b) Coppice Management

"Coppicing" is when trees grow back after they have been cut. It differs from side pruning and pollarding in that the entire tree is cut usually at a height of 10-50cm from the ground.

Some points to remember about Coppicing:

- Is generally done at least once before crop is planted. When coppicing is done before planting the crops, the root die-back reduces competition of the trees/shrubs for water and nutrients.
- The first coppicing should not be done until the trees are 3-4 m high (9 months - 2 years old depending on species and location) to let the root system become well established. If shading becomes a problem before then, the branches should be pruned.
- Repeated coppicing is done as is needed, either when shading is too much on the crops, or when the farmer wishes to harvest branches, fodder, poles, etc.
- Coppices should be left to grow during the dry, fallow periods as their shade helps with moisture conservation and weed control. As far as time of the year is concerned, the only general rule is that coppicing should not be done at the height of the hot, dry season.

How to do coppicing:

- The cut must be angled and clean, usually at between 10 and 50cm from the ground.
- The cut branches are laid on the ground and, after 5-7 days, are shaken to remove dried leaves and small twigs, and the larger sticks are then stacked to dry.
- The leaves and small twigs are incorporated into the soil, often during weeding to save labour. In arid/semi-arid lands, some of the material should be left as mulch.
- Generally there will be many coppices that grow, 2-3 of the largest should be left and the rest removed if the desired product is poles.

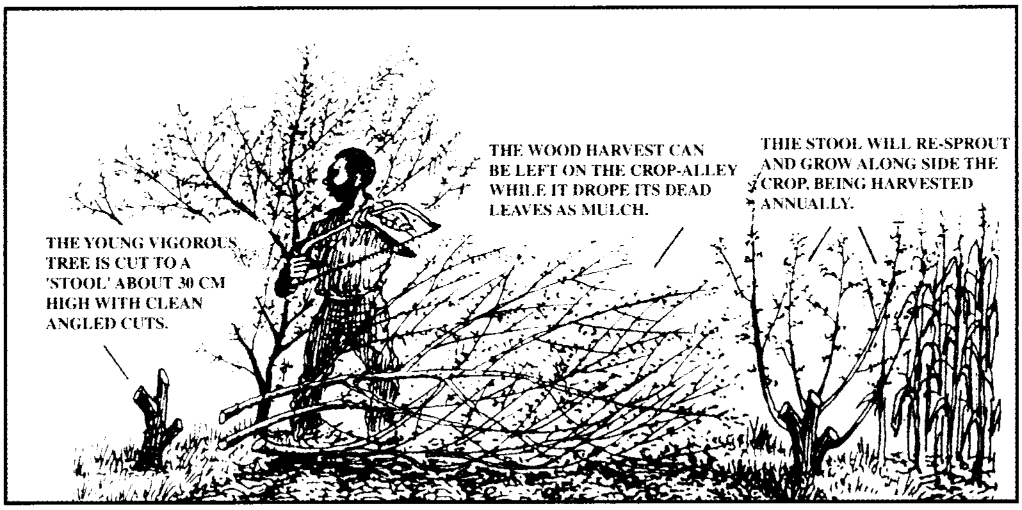


Figure 93 Example of coppicing

(c) Pollarding and pruning

Pollarding is the extensive cutting back of the crown of the tree (at least to get it higher than 2 meters from the ground level) and thus harvest the branches and leaves, and to stimulate the growth of a new, better formed and more productive crown.

Pollarding differs from side pruning in that more of the crown is removed and sometimes the very top of the tree is cut off. The remaining trunk is at least 2 metres high.

Pollarding is done as follows:

- The crown of the tree is either pruned extensively or entirely removed.
- The branches and top are laid between the rows and left for 5-7 days. They are then shaken to remove leaves and small twigs (which are immediately incorporated into the soil by digging or ploughing) and then are stacked to dry for use as poles or fuelwood.
- The cycle is repeated every few years and, perhaps, continued for several decades. The main trunk continues to grow until the farmer chooses to harvest it entirely for timber.
- Side Pruning is done to: minimize shade on the intercrop, and provide more room for tillage operations, harvest branches for mulch, fodder and fuelwood.

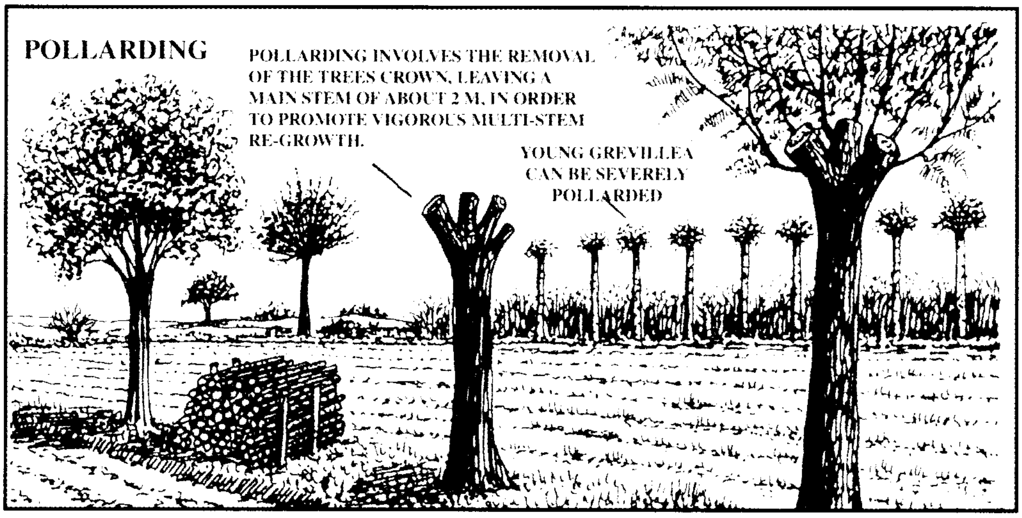


Figure 94 Example of pruning and pollarding

10. Agroforestry Intercropping Systems

The agroforestry systems described in the following pages are not exhaustive and several modifications can be applied.

Traditional agroforestry exists in the Myanmar Dry Zone such as boundary plantations along the contours with multipurpose species, scattered Acacia Catechyu in the crop land, homestead plantations, etc. Unfortunately, those systems have not been properly studied yet and additional attention should be paid to explore the potentials of the existing systems and their possible improvement.

A good rule to bear in mind is that agroforestry is site-specific*:* specific to the growing and farming conditions, and specific to the wants and needs of the farmer. The extension worker should be certain that the farmer is fully aware of, and understands both what can be gained and how to properly manage the agroforestry system proposed for his/her farm so as to reap maximum benefits.

A poorly managed agroforestry plot can lead to drastically reduced crop yields due to over shading of the crops by the trees and/or by a tree/shrub becoming weedy or highly competitive.

Talking about agroforestry may be enough to convince a few farmers. However, many more will be interested in and become enthusiastic about agroforestry if they see it in practice. The extension worker should have at least one well-managed agroforestry plot that can be used as an example to demonstrate correct management techniques and what can be gained from agroforestry. The plot or plots could be on the extension worker farm/ station, on the field of a contact farmer, at a Farmers Training Centre, or all of the above.

Finally, some difficulties of working with agroforestry that an extension worker may encounter are:

- Social constraints (difficulty in introducing agroforestry intercropping systems to an area, taboos about certain species, etc.)
- Training/Education skills to explain about agroforestry.
- Availability of tree seeds or planting material.
- Lack of information on particular areas and species.

Most of these constraints can be solved by training and field experience.

Bearing in mind the above general recommendations the following main agroforestry systems suggested for the Dry Zone are:

- Alley cropping (hedgerows)
- Multilayer Gardening
- Trees/shrubs/grass rows along the contour
- Boundary plantations

ALLEY CROPPING

Definition and scope

Alley cropping is a farming system in which rows of trees or shrubs are planted along contours between rows of crops for soil and crop yield improvement. The hedgerows may be narrow or widely spaced based upon the purposes of the system and the type of crops and trees/shrubs used. The measure is meant to produce biomass for multipurpose uses and increase soil fertility, reduce sheet erosion and increase water storage within soil profile.

Technical specifications

In the establishment of an alley cropping system, the objective should be defined beforehand and designed accordingly. If the primary objective of the system is soil conservation, the major focus would be on maximum erosion control. The important factor determining the effectiveness of hedgerows against erosion is **the density of vegetation in the hedgerows and width of the hedgerows.** The spacing between the seedlings when seedlings are used as well as width of the hedgerows, therefore, should receive due attention. In this case, regardless of the type of planting material used, double hedgerows are preferable to single hedgerows.

When seedlings are used, they need to be planted in double rows (about 40 cm apart) and the seedlings are planted at about 15-20 cm spacing between the seedlings in each row in a staggered pattern. **The vertical interval for an alley cropping, designed for erosion control, is 1 m and the method could be effective for erosion control up to 5% slope range (up to 10% alternate with bunds).**

In general alley cropping should be limited **to slopes not higher than 5% and soils with depth > 100 cm.** For higher slopes, hedgerows should be combined with physical structures. Alley cropping is also recommended in areas receiving > 800 mm rainfall.

When the objective is to obtain and use organic fertilizer, the main factor determining the amount of organic fertilizer (green material) is the spacing between the consecutive hedgerows than the density of vegetation within the hedgerows and width of the hedgerows. Therefore, single hedgerows can be used and the spacing between the seedlings can be 30 cm. The spacing between consecutive hedgerows depends on the amount of green material to be harvested. The wider the spacing the less the amount of materials. The optimum hedgerow spacing, advocated for green material production is 4 m. Under Dry Zone conditions, to avoid competition for water, a 6-8 m spacing is suggested.

Besides these uses, **primary or secondary purposes are also to be considered such as the amount of fodder/timber of fuelwood or both to produce.** In this case, the type of species to select and the pruning/coppicing techniques should be calibrated around those needs.

Suitable species

Suitable tree and shrub species for alley cropping should meet the following set of criteria: establish easily, grow rapidly, have a deep root system, possibly N-fixing, produce heavy foliage, regenerate readily after pruning, are easy to eradicate, and provide useful by-products.

Leguminous trees and shrubs are preferred over non-legumes because of their ability for fixing atmospheric nitrogen. Examples of leguminous trees/shrubs for intensive hedgerow inter-cropping are: *Calliandra calothyrsus, Leucaena leucocephala, Sesbania sesban, Cassia siamea, Gliricidia sepium and Mimosa scabrelia.*

Management of the hedgerows

The seedlings in the hedgerows are first cut when they reach a basal diameter over 6 cm just above the lowest branching at about 10-15 cm height (HT). Such low cutting stimulates strong branching from the tree bottom resulting in the formation of denser/closer branches.

Other management aspects include isolation of the livestock from the field, weeding, gap filling, low cutting, periodical pruning/cutting, etc. Pruning of the hedgerows during cropping is necessary to avoid shading of the companion crop. Pruning intensity varies with shrub or tree species. As a general rule, the lower the hedgerows and taller the crop, the less frequently is pruning needed. Fast growing plants, such as Leucaena and Gliricidia, require pruning every five to six weeks during cropping. Too low or too frequent cutting may cause the premature death of the plants.

Utilization and benefits

The foliage and twigs/small branches from the hedgerows are conserved after dried in the sun for green manuring or livestock feed. The dried material can be conserved and used for livestock in combination with grass hay and crop residues. Its use can substantially increase the digestibility and intake of feed with considerable livestock productivity implication. Likewise the material can be used as organic fertilizers few weeks or days before crop planting depending on the type of species.

Other specifications:

Work norms are difficult to compute since alley cropping is a drastic change on the farming system.

Integration is with physical structures (alternate 2-3 rows of alleys and 1 bund) for slopes > 5% and with other vegetative measures (mulching, etc.). Refer to other sections for additional biological measures.

Inputs are mostly for training, supervision and provision of seedlings.

Limitations refer to difficulties in changing farming system, erratic rainfall and management problems. Under the context of the Myanmar Dry Zone, alley cropping has limited potential and only in better-off areas in term of soils, fertility levels and higher rainfall. Training and testing is essential before wider application.

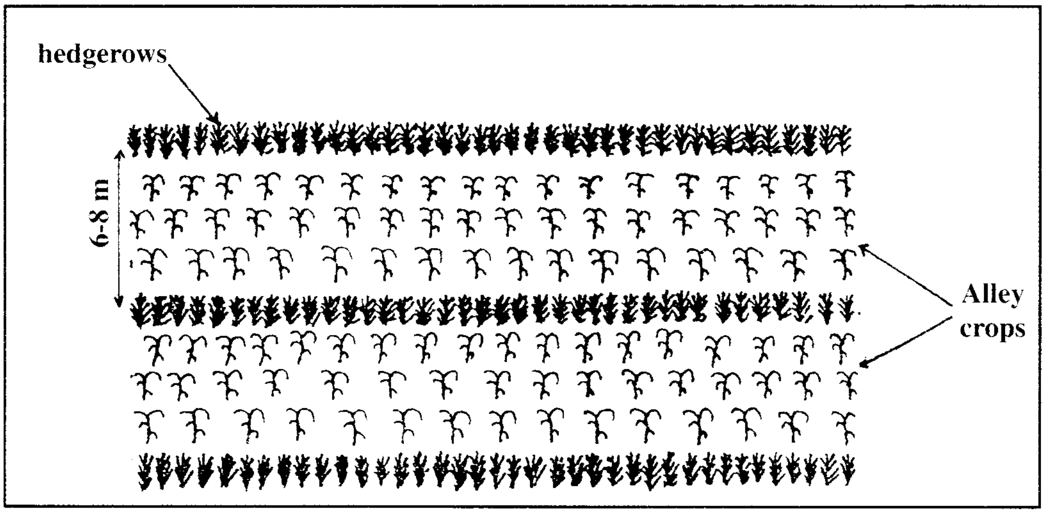


Figure 95 Alley cropping

Example of Alley cropping with Sesbania Sesban (Ethiopia)

MULTI-STOREY GARDENING

Definition and scope

Multi-storey gardening is a way of planting a mixture of crops and trees of different heights and different uses: food crops, cash crops, fruit trees, woody perennials, fodder and forage. It makes the land more productive and improves soil fertility, reduces temperature, provides shade, and increase family income, particularly during a period of drought.

Technical specifications

Suitable sites are soils with good drainage and ***soil depth >100 cm, slope < 5%.*** If possible, the site should be close to a water source and close to the farmers' house to guard fruits against theft. A minimum of 1 acre of land is required for a good mixture of plants.

Choose the trees and crops to grow:

Farmer chose the cash crop to grow.

- Chose the major fruit trees, i.e. those that would provide the highest income, for instance: mango, cashew, tamarind, jackfruit.
- Chose the secondary fruit trees, i.e. those that can grow and produce quickly and provide secondary source of money, for instance: lime, guava, custard apple, drumstick, kapok, castor oil.
- Choose the multipurpose trees: these trees produce poles, post, timber, fuelwood fodder, leaves for vegetables and medicines, for example: leucaena, cassia, calliandra, gliciridia.
- Choose additional mixed-species (woody-perennials or shrubs or grasses) useful for different purposes, for example: sesbania, sisal, napier grass, bamboo, tanaka, sandalwood, etc.

Recommended Spacing

Species	Examples	Spacing	Remark
Major cash crop		closer	As normally practised
Major fruit tree	Mango, cashew, tamarind, jackfruit	30 ft x 30 ft	Planed in rows
Interplanted fruit tree	Lime, guava, custard apple, drumstick, kapok, castor	10 ft x 10 ft 15 ft x 15 ft	Planted in rows between major fruit trees
Multi-purpose tree	Leucaena, cassia, calliandra, gliricidia, toddy palm	12 ft x12 ft for woody species 3 ft x3 ft for fodder species	Planted around the edges of the farm
Mixed species	Sesbania, sisal, Napier grass, bamboo, thanakha, sandalwood, pigeonpea	6 ft x 6 ft or varied	Planted in suitable places in the cash crop or in gaps.

Limitations refer to: weeding, mulching, pruning, pollarding and thinning, which require labour and continuous management. The wrong selection of species may shade or compete with crops and reduce yields.

Multi-storey gardens can be protected by bunds on slightly higher slopes or to divert runoff into the plots.

Other specifications are similar to those explained for alley cropping

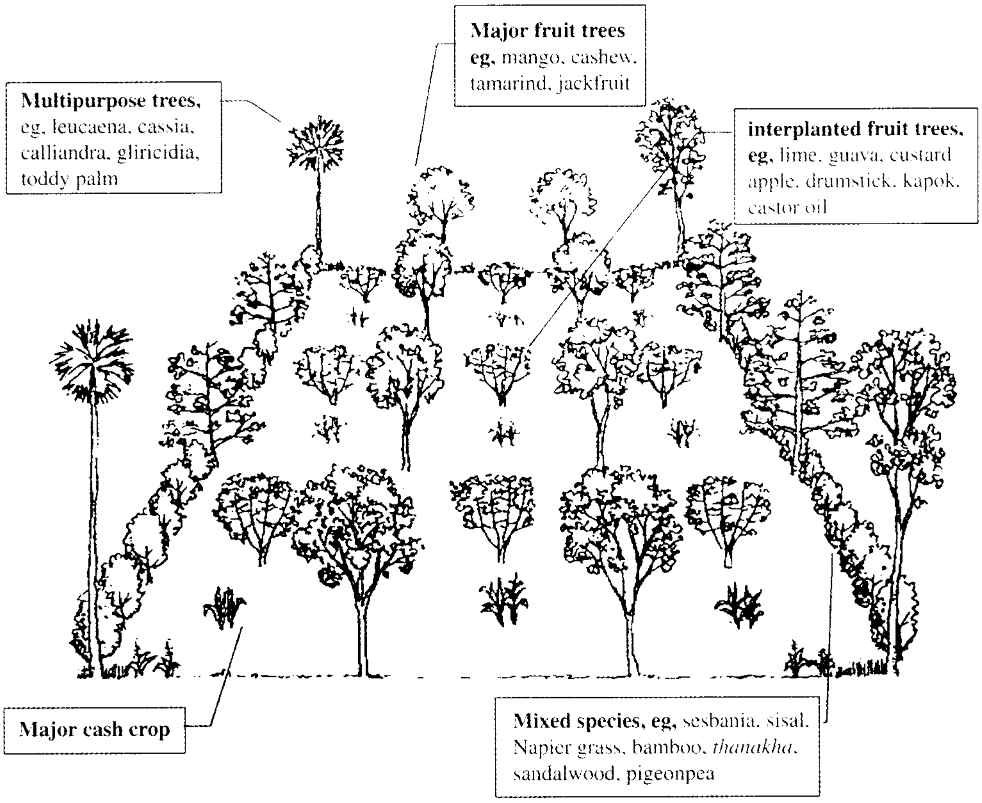


Figure 96 Multi-storey gardening

TREES/SHRUBS/GRASS HEDGEROWS

Definition and scope

A strip of trees, shrubs and grass is planted along the contours at specified intervals in substitution of bunds on gentle slopes and deep soils. The measure is designed to control erosion, improve fertility and provide biomass for multipurpose uses.

Technical specifications

The **measure is suitable for slopes < 15% and soil depth > 100 cm.**

First a row of **trees is planted** at 2 meters (6') spacing apart within the line. Their main purpose is for timber and poles, for instance Acacia catechu. Then shrubs such as Sesbania, Gliciridia and Leucaena are planted in a second row below the first one. The spacing between the first row and the second is 3'. A third row of dense grass is planted by using splits or cuttings below the shrub row. The overall width of the hedgerow is 6' (see figure 97).

Layout should be precise and planting done with care (see specifications for tree planting and grass planting).

The management specifications for this system are similar as those for alley cropping and grass strip establishment respectively.

Limitations and inputs (see above sections).

Integration is with control grazing, intensive management of the rows and the cropped area.

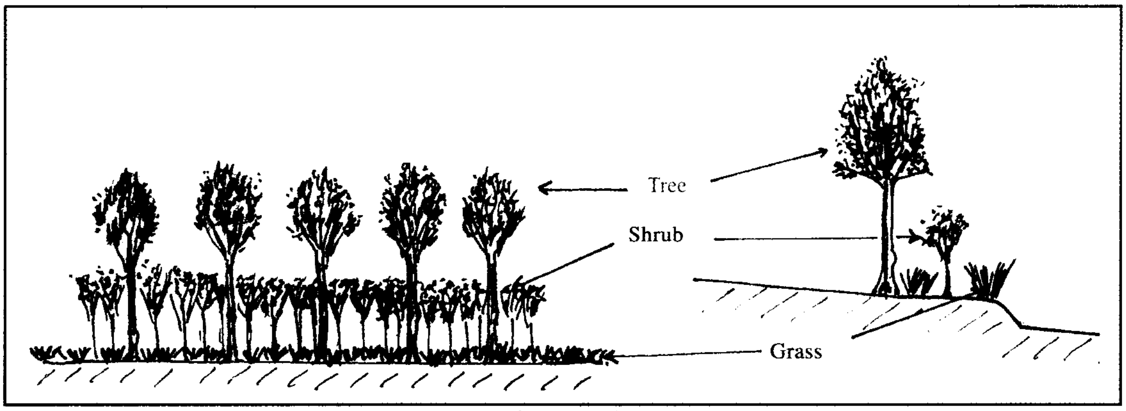


Figure 97 Trees/shrubs/grass hedgerow

Modification to this system

Boundary plantations (see also stabilization of physical structures)

Farm boundaries (with or without bunds) along the contours should be reinforced with trees, shrubs or grass to close the gaps, collect sediments and control erosion, support the benching of the farm boundaries and provide multipurpose vegetative materials.

In several parts of the Dry Zone, farmers' boundaries are already planted with various species of trees and shrubs of multipurpose uses. There is a great potential to improve such boundaries with native and improved species of trees, shrubs and grass.

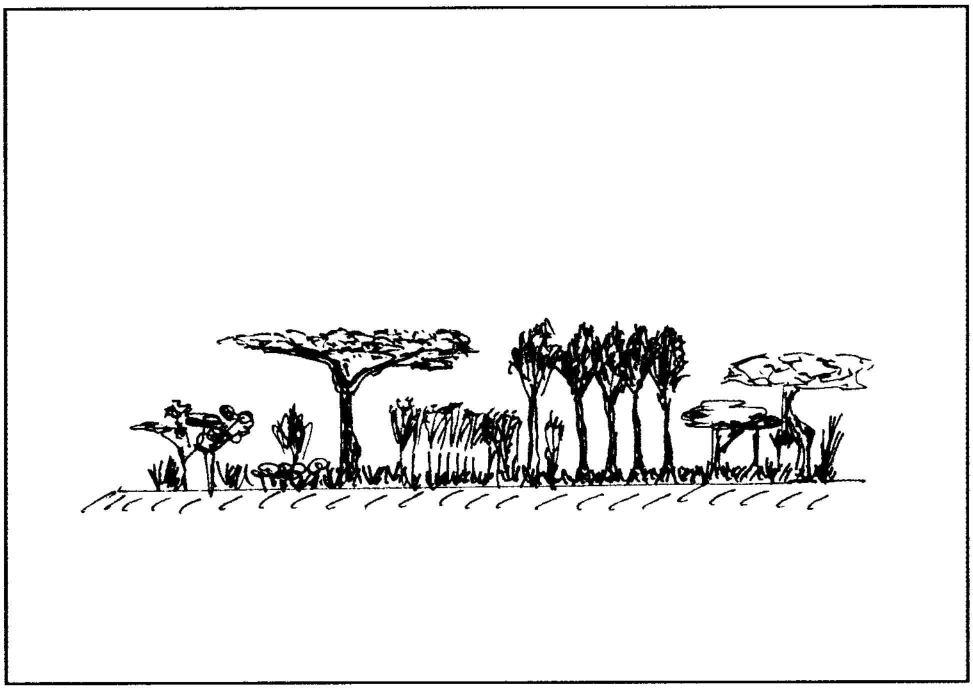


Figure 98 Boundry Plantation

-B

SOIL AND WATER CONSERVATION MEASURES FOR GULLY CONTROL AND REHABILITATION

SMALL STONE CHECKDAMS (GULLY PLUGS)

Definition and scope

A stone checkdam is an obstruction wall across the bottom of a gully or a small stream, which reduces the velocity of the runoff and prevents the deepening and widening of the gully. Sediments behind the checkdam may be planted with crops or trees/shrubs grass and thus provide additional income to the farmer. The excess runoff move to the next structure downstream through a spillway.

Small stone checkdams are mostly used for small gullies and depression areas between fields. They also stabilize small gullies which are tributaries of wider drainage lines checked by series of SS dams or bench terraces. As seen in previous sections (bunds), checkdams serve also as spillways and outlets to evacuate excess runoff from cultivated fields and terraces.

Technical specifications

They can be constructed in a wide range of conditions, for instance in (1) small gullies serving a large one, (2) as stone outlets for traditional or newly constructed bunds or terraces unable to accommodate all runoff and (3) to trap silt before a water pond.

These structures are for gullies having maximum 15' width. Larger gullies require a more complex design, similar to the one described for SS dams.

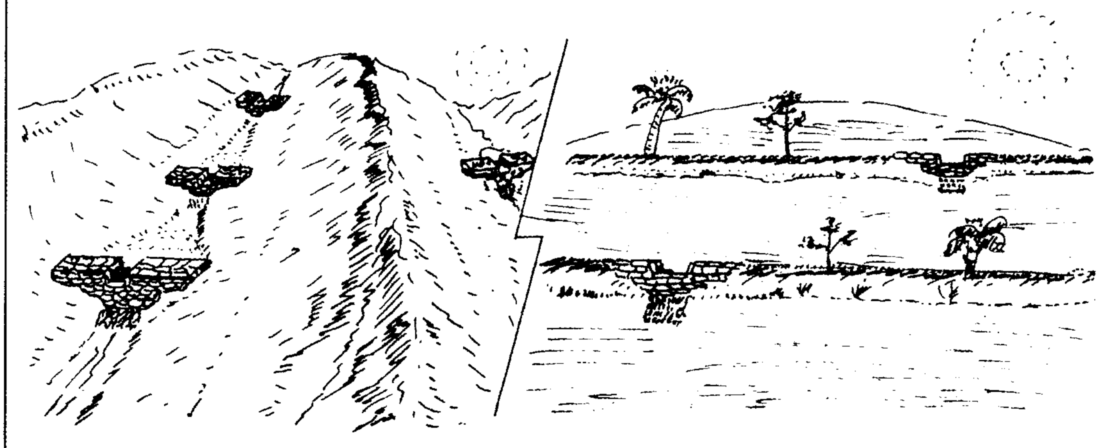

(1) In Small gullies (1) as outlets for bunds/terraces

Figure 99 Checkdams

These structures are for gullies having maximum 15' width. Larger gullies require a more complex design, similar to the one described for SS dams.

Dimensions:

- Small stone checkdams are of **maximum** 1-1.5 meter (3-5') high (excluding foundation), made out of stones, with a bottom key of at least 1.5' and *side key* of 2'.
- The **bottom width** will be 0.6-0.8 times the effective height (from spillway to bottom of the gully floor) of the **checkdam wall** (from 3 to 5'), the **medium width and top width** 0.5-0.7 and 0.4-0.6 times the **height of the checkdam** respectively (rule of the thumb).
- **A spillway** is placed at the center of the checkdam and should be constructed with a free board of 0.75' from the top of the checkdam (1.5-2' total depth), its width 1' less

than the bottom width of the gully to avoid erosion of the sides of the structure during overflow (see figure 100). An apron structure need to be constructed at the foot of the checkdam of at least 2'-3' length to accommodate the water fall.

- **The height of the checkdam should take into account the maximum peak runoff** flow in the gully (signs noticeable on the gully sides) and do not exceed 2' above those marks. This estimation is empirical and do apply for small gullies only.

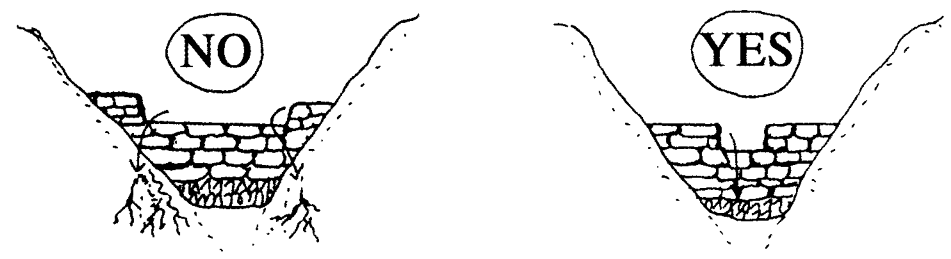


Figure 100

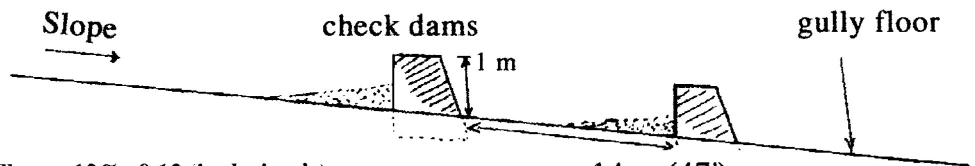
Layout:

- In small gullies start from the top and proceed downwards. The same applies to series of terraces or bunds going to be provided with checkdams.
- Along small gullies estimate the distance between two checkdams by using the following rule off the thumb formula (see example 1):

$$S = \frac{\textbf{1.7 Height}}{\textbf{G (gradient)}}$$

S = spacing apart two checkdams
Height = effective height (excluding foundation) of stone wall which is approximately 3-5' high
G = gradient (slope) of the gully bottom expressed in decimals

Example (1)



G=Slope= 12%=0.12 (in decimals)
H=1 m (3')
S=1.7 x 1/0.12 + 14 meters (47' approximately)

Construction phases:

- Construction start by digging the foundation 1-2' deep and as wide as the bottom width of the checkdam.
- Proceed by making the foundation with large stones and proceed up and laterally following agreed design. Fill space between stones with small ones.

- The downstream wall should be slightly ladder shaped for maximum stability.
- The upstream side of the checkdam should be filled with small stones or pebbles to slow down percolation.
- Place the spillway at the required height. Make sure that side keys are also 1'-2' deep anchored inside the gully banks.
- Complete the structure by constructing the apron. The apron is made out of flat heavy stones placed vertically. Fill gaps between stones with small ones.

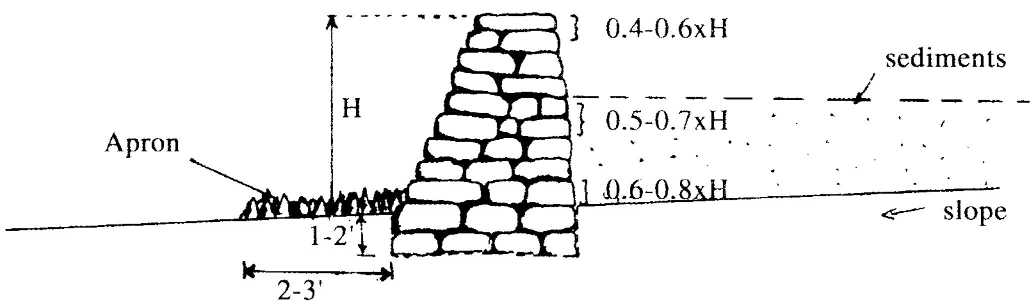


Figure 101 Example of well shaped stone walls

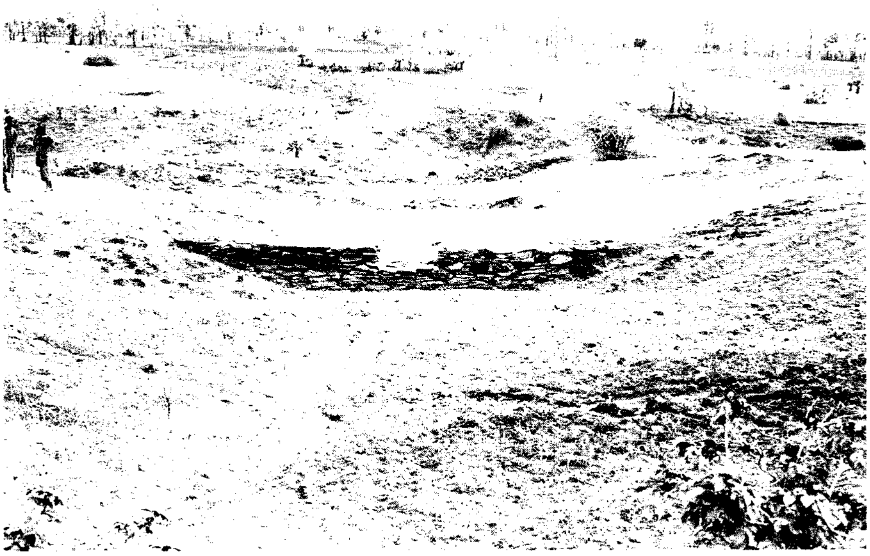
The gully sides are reshaped and soil filled against the checkdam wall. Gully sides should be planted with rows of grass and possibly reinforced with plants such as Sisal placed along the upper and/or lower side of the dam.

The work norm is estimated of about 1 person per 4'-6' of linear work per day (depending from availability of stones). In the project areas, a 3' of linear work is assumed to be the norm, including excavation of the key trenches and transport of stones. ***The inputs*** required are stones (avoid round shaped stones), tools, labour and planting material for revegetation.

Maintenance and management: raise the checkdam if necessary. Maintain stone walls after damage caused by intense showers.

Training requirements (same as SS dams).

Limitations refer to the availability of labour and stones. Stones may be brought from adjacent areas (costs increase). Unstable soils should not be treated with checkdams (sodic, sandy) since they can not anchor properly and can easily be by-passed by water. They should rather be treated with vegetation.



Stone checkdam across a small gully in Yaw Gyi Taw - Kyaukpadaung

Stone checkdam full of sediments after rains

GABION CHECKDAMS

Definition and scope

A gabion checkdam can be a large or small structure. For practical reasons only small gabion checkdams are mentioned here. It consists of galvanized iron steel wire cages, usually 2m x 1m x 1m size, filled with loose rocks/stones. The cages are placed close together and tightly tied with wire. Their function is the same as stone checkdams.

Technical specifications

For small gabions, the general design criteria for the stone checkdams should be used for spillway design. For larger structures apply the criteria used for SS dams. The spillway should be adequate to allow the peak flows, without overtopping.

Gabion checkdams require stable soils or subsoil for proper anchorage (same as stone checkdams).

A good gabion checkdam should have a proper key, an adequate spillway, an apron and a correct configuration.

An apron extending $^{1}/_{2}$ times the spillway height is necessary.

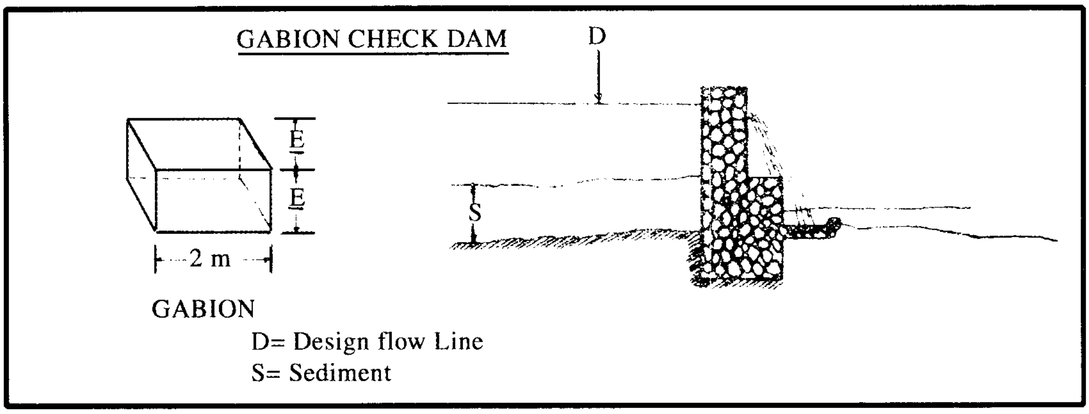
A key trench, 1 m deep and as wide as the width of the dam should be dug in the underlying soil. The key trench should extend at least 1 m into the abutment wall, right up to the height of the dam. The gabion key trench should be filled with ***small stones.***

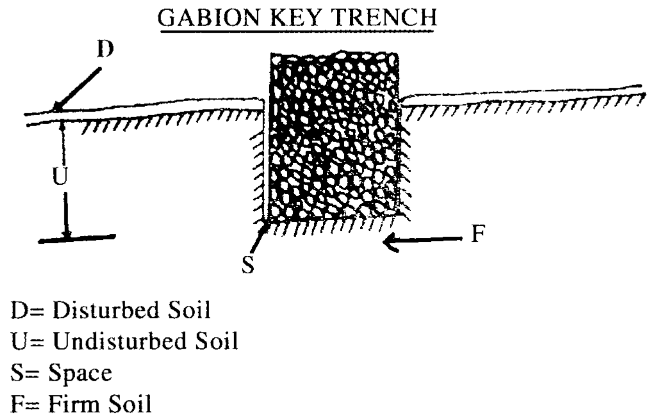
Small gabion checkdams are generally constructed not more than 4 meters high. The stepped placement of the gabions allows greater stability of the dam, to withstand the pressure of the impounded water.

Materials used for filling the gabion: the stones should be hard and of different sizes. The stones should be placed tightly together so that no large voids are created. If there are large voids, the stones get realigned when the water flows through them. This may result in sinking of the dam. If small stones are used, they should be placed in the centre of the gabion, with larger stones facing outside.

Limitations: the measure is more expensive but may be lasting longer if well constructed.

Other specifications are the same as for stone check dams





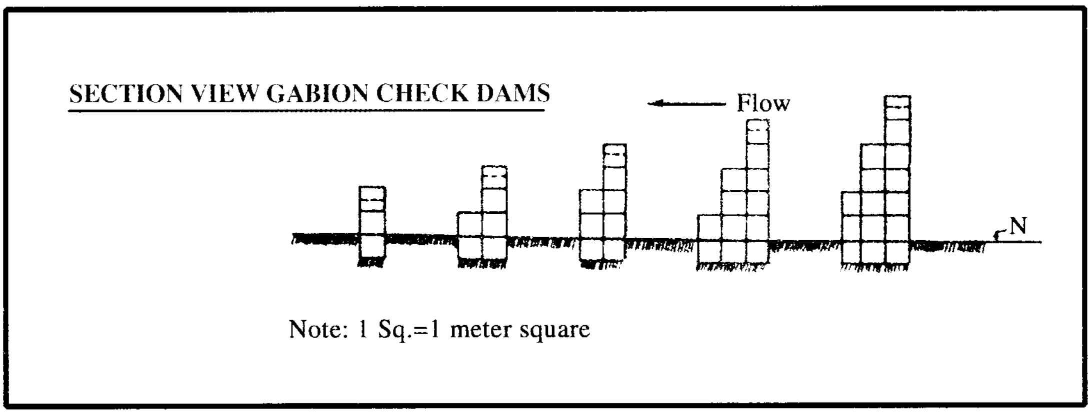


Figure 102 Gabion Checkdams

BRUSHWOOD CHECKDAMS

Definition and scope

Brushwood checkdams are temporary structures constructed with trees, branches, poles and twigs. Plant species which can easily grow vegetatively through shoot cuttings are ideal for this purpose. The objective of these dams is to retain sediments and slowdown runoff, and enhance the revegetation of gully areas. They are constructed either in single or double row, in areas without stones .

Technical specifications

Brushwood checkdams are suitable only for small gullies of less than 2 m depth.

Brushwood checkdams should be combined with planting of multipurpose plant species, preferable having vegetative propagation (elephant grass, bamboo, etc.).

A properly constructed brushwood check dam require considerable amount of planting material and these may be a constraint in the Dry Zone. Straight branches of 3-6 cm diameter should be found. The thicker branches will be used as vertical posts. Their height depends from the height of the gully but should not be more than one meter above the ground. The vertical posts should be driven into the soil at least 50-60 cm depth, spaced apart 30-50 cm. They should also gently lean backslope for better resistance. After the posts are driven into the soil, the thinner branches or limbs are interwoven through the posts, to form a wall. Each branch should be pushed into the banks, up to 50 cm inside. If vegetative materials are used, these branches will strike roots into the banks and strengthen the dam. The soil at both ends of the dam is carefully patched down with feet. No soil should be dumped in the middle part of the dam.

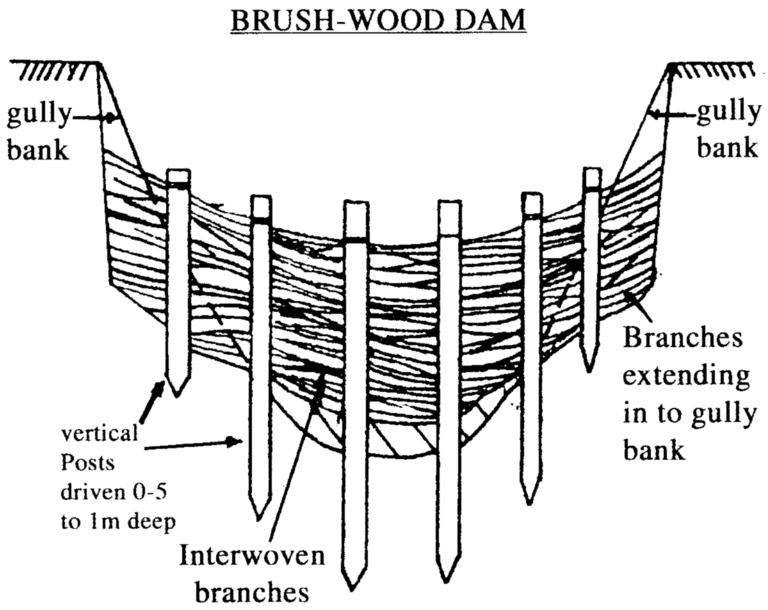
Spacing of the brushwood checkdams: As a simple rule of the thumb for the distance between the two successive dams is that the bottom of the upper checkdam should be level with the tops of the poles of the lower one. Another rule would be to use the same calculation for stone checkdams and divide the distance by two or three.

The brushwood checkdam should be reinforced with plants such as Sisal placed along the upper and/or lower side of the dam.

Maintenance is often required because damage can easily occur, particularly at the corner of the dam adjoining the banks. Extra poles and branches should be placed accordingly.

Limitations refer to availability of planting material and maintenance. In this respect only small gullies are recommended for this measure.

Other specifications: same as for stone checkdams.



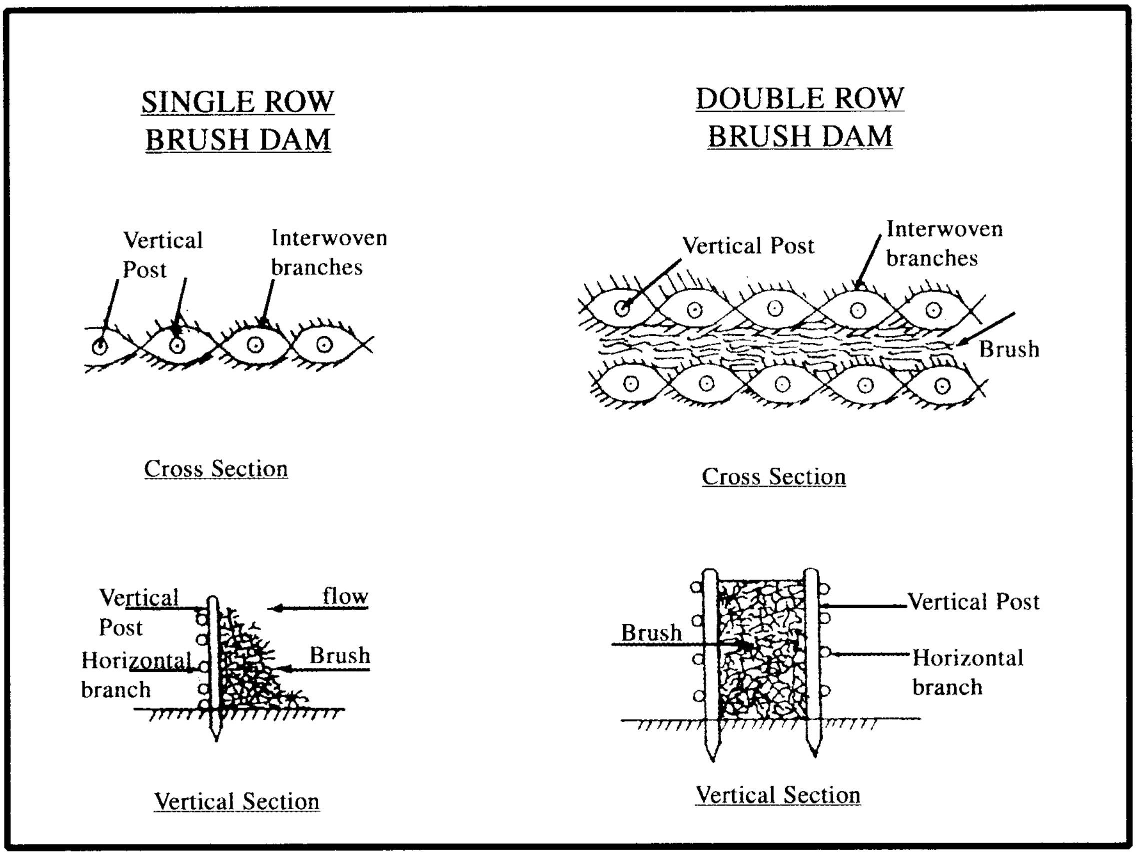


Figure 103 Brushwood checkdam

GULLY REVEGETATION

Definition and scope

Revegetation of a gully is the plantation of the gully sides and bottom with multipurpose species so that it reduces runoff and control erosion, support and enhances the stability of physical structures such as checkdams. Besides, it allows unproductive areas to supply useful biomass for different purposes.

Technical specifications

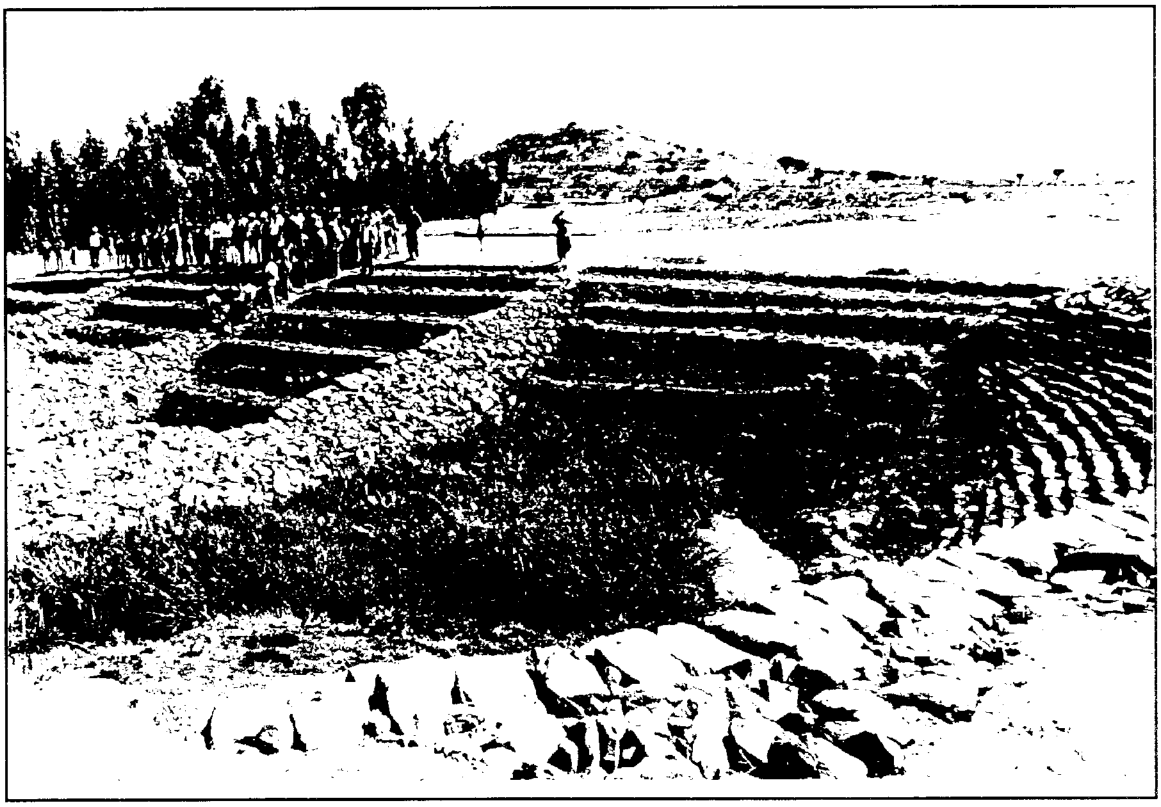
Three conditions and steps are important for revegetation:

- **Exclude the cattle throughout the year and use cut and carry.**
- **Reshape the steep gully sides**. Reshaping can be done either by cutting the edges or **shaping the slope in grades or steps for tree/grass planting.**
- **Plant trees and grass which are drought resistant and colonize the soil rapidly.** Elephant grass, Rhodes, Buffle grass and suitable native grass are recommended. For trees/shrubs, Sesbania sesban, Prosopis and Acacia species. Other species include Sisal and euphorbia. **The gully edges** adjacent to the fields should be stabilized with strong rooting trees and vegetation to impede the widening of the gully and clumping.

The revegetation of a gully is always combined with physical structures (checkdams, etc.).

The main limitation refer to the cattle interference. It is suggested to start with small portions of a gully as a demonstration.

Management and maintenance refer to all operations meant to improve and use by-products (see biological measures and agroforestry).



Gully control with checkdams + revegetation (in ladder shaped sides)

F-

ANNEX 1 FARMING SYSTEMS IN THE DRY ZONE

MAIN ASPECTS OF THE FARMING SYSTEMS IN THE DRY ZONE

In summary and in relation with the causes-effects of land degradation and poverty, the following elements of the farming system and socio-economic conditions should be retained:

The cropping pattern is summarized in the tables given below. Generally, considerable variations to the cropping pattern occurs in Kyuakpagdaung and other townships with similar characteristics due to the differences in soils, topography and rainfall (presence of hardpans, low infiltration etc.) This results in the reduction of the number of crops that can grow during the early and late monsoon (ground nuts and late sesame virtually absent). Paddy fields are mostly grown at the bottom of wide spread gullies checked by traditional overflow earth dams.

Magway and neighbouring townships benefits from higher rainfall and wider range of options (runner type of ground nuts, late sesame, pulses).

Chang U and adjacent townshis have rice growing in the lowland areas. Otherwise its cropping pattern does not differ from the others significantly.

For simplicity, three townships, namely Kyaukpadaung, Magway and Chaung U, are taken as a reference to describe the main farming systems existing in the Dry Zone. Variations for each and every township should be then modified or revised accordingly.

In the three townships, pigeon peas are grown in pure stands or in rows. Intercropping is also common, increasing from south to north due to the unreliablity of rainfall. Double cropping is the main pattern (first sesame, then other crops) except for pigeon peas, runner type of ground nuts and short staple cotton.Late sorghum is planted as second crop mainly for animal feed (bullocks) and rarely for human consumption (only in bad years). Millet is also planted along traditional bunds and in poor soils (animal and human consumption). Toddy palms are fund around farm boundaries and along bunds/earth dams across gullies. Vegetable gardens are found around rivers and streams, mostly in Magway and Chaung U. Onions are a most valuable cash crop planted in those areas.

Crops residues are extensively used for animal feed (by - products of oil crops, peas, beans etc). Sorghum is a typical fodder crop. Due to lack of fuelwood, the stems of pigeon peas are also burned for domestic use. Most sesame straws are either sold or used for the jaggery industry. Traditional farm yard manure preparation is common although compost quality is often poor (lack of sufficient and homogeneous breakdown, leaching and loss of nutrients, poor conservation, lack of watering, etc.) Farm yard manure is extensively used but also sold.

Livestock is very important. Cattle is mainly used for draught power and transportation of farm products and water The number of cattle owned is based on the feed and water availability. Sheep and goats are also common, mainly in Kyaukpadaung and Chaung U. They are important for small scale farmers. Many of the landless households own sheep and goat. They mostly graze in waste lands and marginal areas (degraded), further affecting the environmental situation. Pigs are also important and they are fed with a mixture of kitchen waste, tamarind seeds, boiled sorghum seeds, rice bran and ground nut cakes. The pigs are often owned by better - off farmers since feed is expensive. Livestock marketing is reported not to be a problem.

Deforestation and encroachment into public and state owned forests is high. The result is that upper parts (and sloping) of watersheds are the source of severe erosion (high runoff) that generate a cumulative effect on downstream areas, damaging cultivated fields, increasing gullies, increasing salinity and decreasing the recharge of ground water tables. There is no interest from the community to protect surrounding watersheds, since they are managed by the Ministry of Forestry. Marginal lands and bad lands (gullies) are used as temporary grazing reservoirs and there are no efforts to protect and plant those areas since land use rights are not defined. Nowadays, the possibility to lease on a 30 years basis (transferable to heirs) portions of marginal and waste land under the public forest denomination may encourage farmers to rehabilitate some of these areas for forestry or forage production.

Water sources and supply is insufficient, particularly during the dry season. The prolem is servere in several areas of Kyaukpadaung township where the availability of fresh and clean water is scarce. Several of the streams have slaine water and few springs are flowing in the area. Villagers have often to travel long hours to fetch water and walk the cattle long distances. The limited number of water points also increases the concentration of animals around few areas with teh consequent degradation and overgrazing problems.

Land holding size has considerably reduced as a consequence of increase population, fragmentation (division of the land to all children, both male and female) and land degradation.

Over one fifth-one third (depending on conditions) of the village households in the Dry Zone are landless. They are ofteh hired labor for the rest of the farmers during peak periods of cropping activites. They also usually migrate (particularly in Kyaukpadaung) seeking for employment in other regions for 3 to 6 months and return during the cropping season. Outmigration also apply to small farmers that do not have sufficient land to sustain their livelihood throughout the year. Level of indebtedness is generally high among landless and small farmers.

Land holding size

- Kyaukpadaung 22% less than 2 acres
- Magway 10% less than 2 acres
- Chaung U 17% less than 2 acres

The average holding size for family is

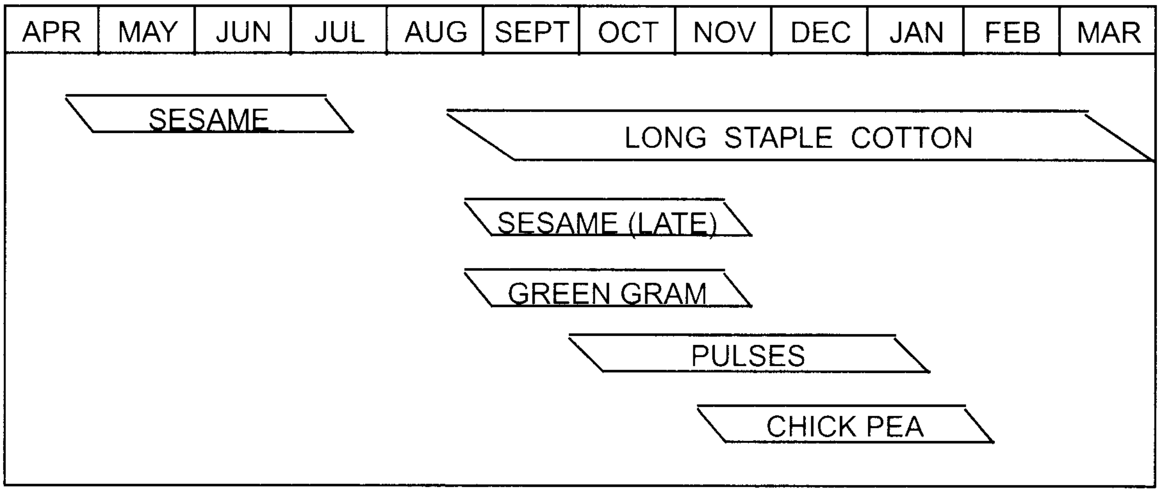
- Kyaukpadaung 5.8 acres
- Magway 7.4 acres
- Chaung U 7.0 acres

7-10 acres are roughly estimated to be the minimum size of holding needed to sustain an household throughout the year (normal rainfall year. not applicable in poor soils).

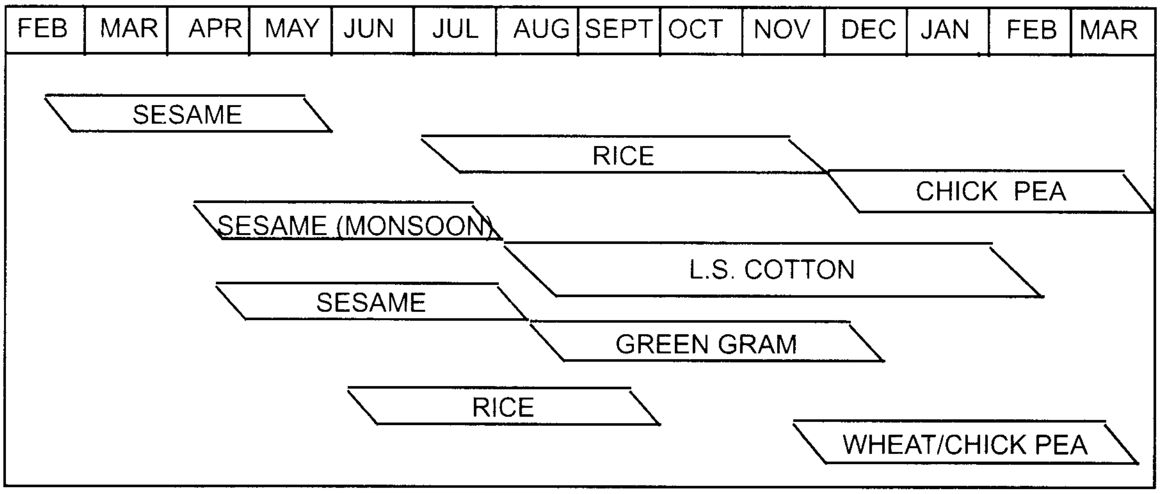
A wide disparity of wealth is observed between the different villages and households within villages. The productivity is generally low and there is limited possibility specially for poor resource households to invest in income generating activities or land protection and rehabilitation activities.

The lack of accessibility particularly in serveral areas of Kyaukpadung township, is a serious constraint regarding marketing provision of basic services and inputs supply.

Cropping patterns in the Dry Zone



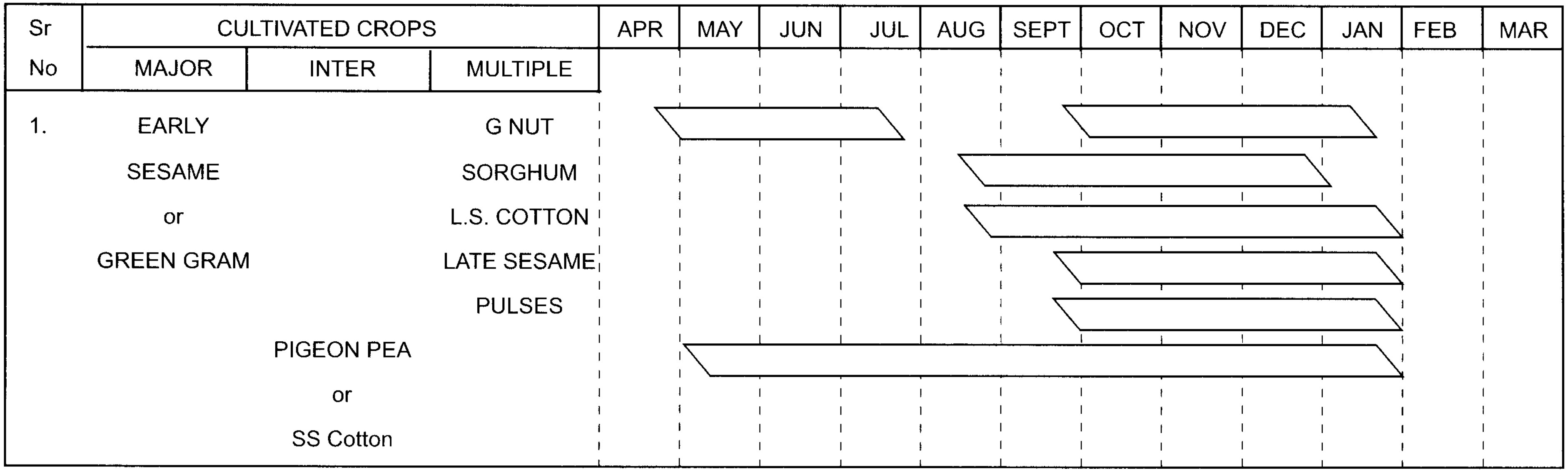
CHAUNG U TOWNSHIP: CROPPING PATTERN (Upland areas)



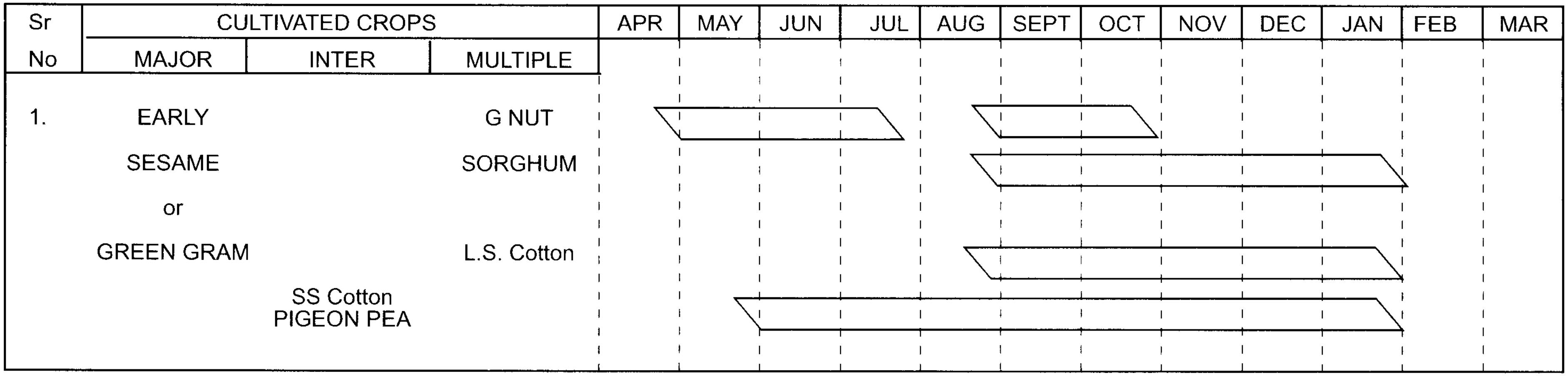
CHAUNG U TOWNSHIP: CROPPING PATTERN (Lowland areas)

Cropping patterns in the Dry Zone

MAGWAY TOWNSHIP: CROPPING PATTERN



KYAUKPADAUNG TOWNSHIP: CROPPING PATTERN



ANNEX 2 TOOLS AND TECHNIQUES FOR SURVEY OF SOILS AND LAYOUT OF SWC MEASURES

How to Identity the texture of a Soil

(a) Definition:

Soil Texcture is mainly concerned with the size and shape of the mineral particles of the soil. Particles are sand, silt and clay and they have the following diameters:

Sand : 0.05-2mm (particles visible)
Silt : 0.002-0.05 mm (particles hardly visible)
Clay : less than 0.002 mm (particles not visible)

Clayey soils have more than 50% clay particles.
Silty soils have more than 50% silt particles.
Sandy soils have more than 50% sand particles.
Loams are soils with mixed particles of sand silt and clay.

(b) Significance of soil texture for soil conservation.

Soil erosion depends much on the infiltration rate of a soil. The infiltration rate again depends on the soil texture. In a sandy soil, the infiltration rate is higher than in a silty soil. In a clayey soil, it may be initially high (for heavy black clay with cracking), but becomes low when the soil is moist to wet. Other factors influencing the infiltration rate are soil structure, humus content, soil moisture, soil depth and soil surface roughness.

In moist agroclimatic zones, the decision for selecting graded or level structures on cultivated land mainly depends on the soil texture found on the slope where conservation is planned. For clayey soil, graded structures are recomended because the infiltration in the basins is too slow. For silty to sandy soil, level structures are recommended because the water retained in the basins will infiltrate more quickly.

(c) How to differentiate between clayey, silty and sandy soil:

1. Take a small handfull of fine earth from the slope.

2. Slowly add little amounts of water and mix it very well with the earth sample. Stop adding water as soon as the formed soil ball starts to stick to your hand.

3. The soil texture can be roughly estimated with your moist soil sample. Try to form the sample into the different shapes demonstrated on the next page. See how many of the pictures you can form with your soil. If you cannot form it any further , stop at the previous picture and read the soil texture on the right side. This is the texture of your soil.

Now proceed to the next page and start forming your soil sample following the pictures from top down.

(d) *form your sample according to each picture below until the next one is no more possible.*

(1) The soil remains loose and single grained and can only be heaped into pyramid:

Sand 1

(2) The soil contains sufficient silt and clay to become somewhat cohesive and can be shaped into a ball that easily falls apart:

Loamy sand (2)

(3) The soil can be rolled into a short thick cylinder.

Silt loam (3)

(4) The soil can be rolled into a cylinder of about 15cm length:

Laom (4)

(5) The soil can be bent into a U:

Clay loam (5)

(6) The soil can be bent into a circle that shows cracks:

Light clay (6)

(7) The soil can be bent into a circle without showing cracks:

Heavy clay (7)

Note: Texture classes (1) to (4)are sandy to silty soils which have generally good infiltration. Texture classes (5) to (7) are clayey soils which generally poor infiltration.

Making Contour Lines with the Line Level

(a) Definition:

Contour lines are horizontal lines across the slope joining points of the same elevation. Contour lines are used to line out conservation measures which have to be level.

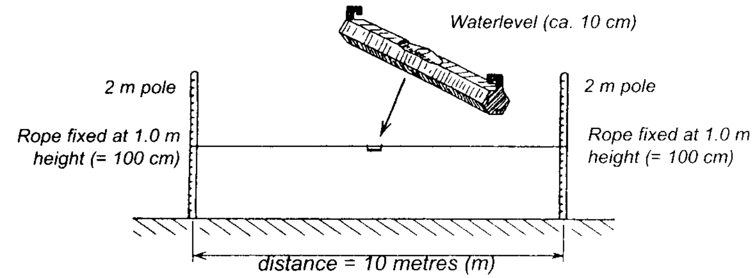
(b) Materials:

The following items are needed:

- Water level
- Thin plastic poles, 11 m long
- 2 wodden poles, 2 m long, marked every 10 cm
- Meter-band or meter-stick
- Short poles for marking on the ground

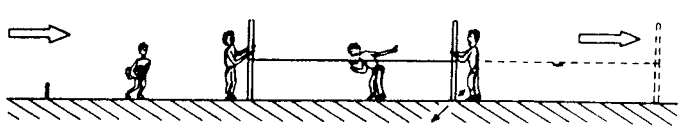
(c) Peparation

Fix the thin rope with each end to one wooden poles so that exactly 10 m of rope are between the poles. Check length regularly. Mark the middle of the rope at 5m with knod. Hang the small waterlevel in the middle of the rope. Three to four people are needed to survey a level line and to mark it on the ground.



(d) Marking contour line:

Proceed across the slope as shown in the drawing below. Survey 10 m at a time, in difficult topography only 5 m (half the rope).



Measuring Slope Gradients

(a) Definition:

Slope gradient is the steepness of a slope. It is given as height in percentage of length (%) or in degree.

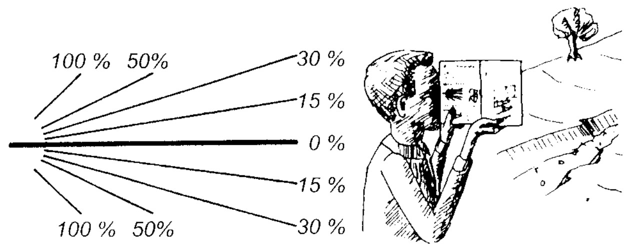
(b) Materials:

The following items are needed:

- Waterlevel or this page of the book (see c) below
- Thin plastic rope, 11 m long, meter band or meter stick
- 2 wodden poles, 2 m long, marked every 10 cm
- Small poles for marking on the ground

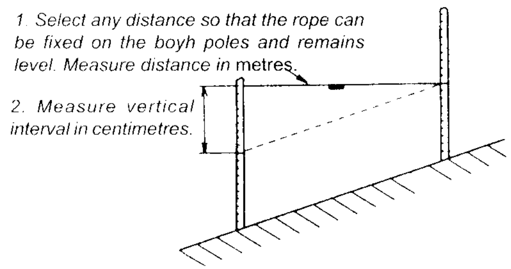
(c) Estimating slope gradients with the figure below:

Hold the book horizontally as demonstrated (somebody may help you in checking) and look with one eye along the book upslope or downslope. Select the line that best fits the actual slope and read the percentages given or an estimation between two lines.



(d) Measuring slope gradients with the line level:

Follow the steps given below and use the formula to calculate the slope percentage. Take care that you use the correct units (1 metre = 100 centimetres, cm)



$$\text{Slope in \%} = \frac{\text{Vertical interval in centimetres}}{\text{Horizontal distance in metres}}$$

Measuring Vertical Intervals with the Line Level

(a) Definition:

A vertical interval between two points is the difference in elevation between them. Vertical intervals are used along the slope to mark the spacing between two conversation measures. Vertical intervals of structures on slopes steeper than 15% are calculated on the basic of the depth of soil observed on the slope.

(b) Materials:

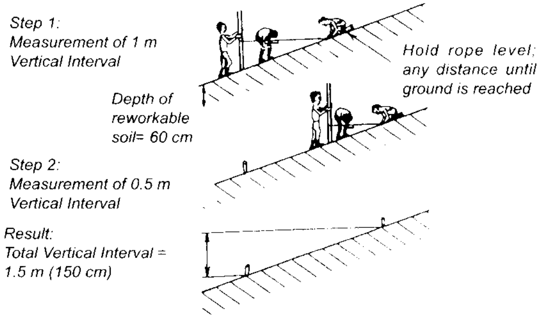
As 4.b) on left page

(c) Assessing the correct vertical interval:

- On slopes of less than 15% gradients (see page 86 for slope measurement), The vertical interval is 1 metre.
- On slopes of more than 15 % gradients, the vertical interval is two and a half times the soils depth.
- Examples:

Slope(%)	Depth of Soil	Vertical Interval, m (cm)
5	(mor than 50 cm)	1 m (= 100 cm)
10	(mor than 50 cm)	1 m (= 100 cm)
18	60 cm (= 0.60 m)	1.50 m (= 150 cm)
25	80 cm (= 0.80 m)	2.00 m (= 200 cm)
35	50 cm (= 0.50 m)	1.25 m (= 125 cm)
45	25 cm (= 0.25 m)	0.62 m (= 62 cm)

(d) Marking 1.5 m (150 cm) vertical interval:



Marking Graded Lines with the Line Level

(a) Definition:

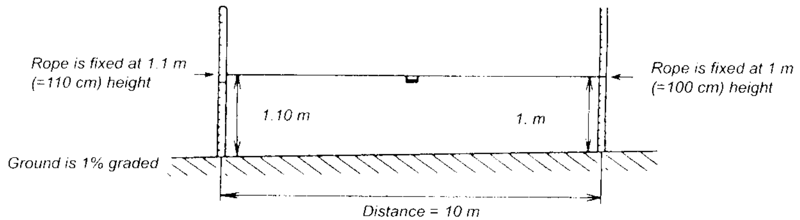
Graded lines are lines across the slope, which have a very small lateral gradient. They are used to line out conversation measures which are graded to drain excess water.

(b) Materials:

As 4.b) on left page

(c) Preparation:

For lining out 1 % graded mesures, the line level also uses a difference of 1 % over 10 m length. That means the rope has to be fixed on the poles with 10 cm difference as shown below:

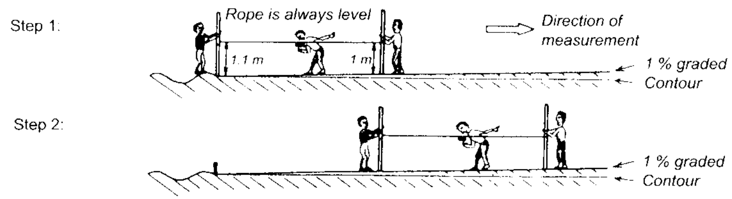


For lining out 2 % graded measures, fix one end of the rope at 1.2 m (=120cm) on the pole, and one end at 1 m (= 100 cm) to give a total difference of 20 cm over 10 m length.

For 0.5 % graded measures, fix rope with 5 cm difference.

(d) Marking 1 % graded lines on ground:

Always start lining out at waterway or river and proceed slightly upslope(1%). Always use the pole with the rope fixed higher up, nearer to the waterway, and the pole with the rope fixed at 1 m, farther away, as shown below.



ANNEX 3 TABLES FOR AVERAGE SPILLWAY DESIGN

TABLE 1 CROSS SECTIONAL AREA (a) OF A MEDIUM STONE RIPRAP SPILLWAY (m2)

RUNOFF COEFFICIENT (K) / CATCHMENT AREA (HA)	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
20	0.37	0.74	1.11	1.46	1.85	2.22	2.59	2.96	3.33
25	0.46	0.93	1.39	1.85	2.31	2.78	3.24	3.70	4.17
30	0.56	1.11	1.67	2.22	2.78	3.33	3.89	4.44	5.00
35	0.65	1.30	1.94	2.59	3.24	3.89	4.54	5.19	5.98
40	0.74	1.48	2.22	2.96	3.70	4.44	5.19	5.93	6.67
45	0.83	1.67	2.50	3.33	4.17	5.00	5.83	6.67	7.50
50	0.93	1.85	2.78	3.70	4.63	5.56	6.48	7.41	8.33
60	1.11	2.22	3.33	4.44	5.55	6.66	7.77	8.88	9.99
70	1.30	2.59	3.89	5.19	6.48	7.78	9.07	10.37	11.67
80	1.48	2.96	4.44	5.93	7.41	8.89	10.37	11.85	13.33
90	1.67	3.33	5.00	6.67	8.33	10.00	11.67	13.33	15.00
100	1.85	3.70	5.56	7.41	9.26	11.11	12.96	14.81	16.67
110	2.04	4.07	6.11	8.15	10.19	12.22	14.26	13.30	18.33
120	2.22	4.44	6.67	8.89	11.11	13.33	15.56	17.78	20.00
130	2.41	4.81	7.22	9.63	12.04	14.44	16.85	19.26	21.67
140	2.59	5.19	7.78	10.37	12.96	15.56	18.25	20.74	23.33
150	2.78	5.56	8.33	11.11	13.89	16.67	19.44	22.22	25.00
160	2.96	5.93	8.89	11.85	14.81	17.78	20.74	23.70	26.67
170	3.15	6.30	9.44	12.59	15.74	18.89	22.04	25.19	28.33
180	3.33	6.67	10.00	13.33	16.67	20.00	23.33	26.67	30.00
190	3.52	7.04	20.56	14.07	17.59	21.11	24.64	28.15	31.67
200	3.70	7.41	11.11	14.81	18.52	22.22	25.93	29.63	33.33

TABLE 2 **BASE WIDTH (B) IN METRE OF A MEDIUM STONE RIPRA SPILLWAY WITH THE PERMISSIBL DEPTH (D) OF 0.75 AND SIDE SLOPE (Z) OF 1.0 (TOTAL DEPTH (D) IS 0.75 + 0.5 = 1.25M)**

RUNOFF COEFFICIENT (K) / CATCHMENT AREA (HA)	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
20	-	-	-	1.22	1.72	2.21	2.70	3.20	3.69
25	-	-	-	1.72	2.33	2.96	3.57	4.18	4.81
30	-	-	1.48	2.21	2.96	3.69	4.44	5.17	5.92
35	-	0.98	1.84	2.70	3.57	4.44	5.30	6.17	7.10
40	-	1.22	2.21	3.20	4.18	5.17	6.17	7.16	8.14
45	-	1.48	2.58	3.69	4.81	5.92	7.02	8.14	9.25
50	-	1.72	2.96	4.18	5.42	6.66	7.89	9.13	10.36
60	-	2.21	3.69	5.17	6.65	8.13	9.61	11.09	12.57
70	0.98	2.70	4.44	6.17	7.89	9.62	11.34	13.00	14.81
80	1.22	3.20	5.17	7.16	9.13	11.10	13.08	15.05	17.02
90	1.48	3.69	5.92	8.14	10.36	12.58	14.81	17.02	19.25
100	1.72	4.18	6.66	9.13	11.60	14.06	16.53	19.00	21.48
110	1.97	4.68	7.40	10.12	12.84	15.54	18.18	16.98	23.69
120	2.21	5.17	8.14	11.10	14.06	17.02	20.00	22.96	25.92
130	2.46	5.66	8.88	12.09	15.30	18.50	21.21	24.93	28.14
140	2.70	6.17	9.62	13.08	16.53	20.00	23.45	26.90	30.36
150	2.96	6.66	10.36	14.06	17.77	21.48	25.17	28.88	32.58
160	3.20	7.16	11.10	15.05	19.00	22.96	26.90	30.85	34.81
170	3.45	7.65	11.84	16.04	20.24	24.44	28.64	32.84	37.02
180	3.69	8.14	12.58	17.02	21.48	25.92	30.36	34.81	39.25
190	3.94	8.64	13.33	18.01	22.70	27.40	32.09	36.78	41.48
200	4.18	9.13	14.06	19.00	23.84	28.88	33.82	38.32	43.69

F

ANNEX 4 LIST OF SOME POSSIBLE EXOGENOUS FORAGE GRASS AND LEGUME SPECIES SUITABLE FOR THE DRY ZONE

LIST OF SOME POSSIBLE EXOGENOUS GRASSES FOR THE DRY ZONE

SUMMARY

GRASSES

- Cenchrus ciliaris (Buffle)
- Chloris gayana (Rhodes)
- Sorghum almum (Columbus)
- Panicum maximum (Green Panic)
- Panicum coloratum
- Andropogon gayanus (Gamba grass)

LEGUMES

- Macroptilium atropurpureum (Siratro)
- Lablab purpureus (Lablab)
- Stylosanthes guinanensis (Stylo)
- Stylosanthes Hamata (Varano Stylo)
- Desmodium sp.

DESCRIPTION

Note: The information provided for each of the species is extracted from the books *Tropical Grasses and Tropical Forage Legumes* produced by FAO and available in the FAO Plant Production and Protection series. For further reading please refer to these books and other reference material on the subject. Remember that the species mentioned in this list may not be all suitable for the Dry Zone of Myanmar. However, some would certainly be of value and should be tried under different soil conditions. The list of species below are those potential grass and legume for improvement of closed areas, ley pastures, improvement of fallow lands and stabilization of physical structures. Based upon the different site conditions (soil texture, reaction, fertility, land use, etc.), select the most suitable species or combination of species for your area.

GRASS

Cenchrus ciliaris

Common names: Buffle grass

Description: It is a tufted and spreading perennial, 12-120 cm tall and deep rooting.

Rainfall requirements: 375-750 mm

Drought tolerance: Very good.

Soil requirements and tolerance to salinity: light textured soils are the best. It is slow in black cracking soils, but when established it does well. Moderate tolerance to salinity.

Ability to spread naturally: spreads well by seeds.

Sowing method, seeding rate, sowing depth and cover: surface sowing or not deeper than 1 cm, preferably in 30cm apart rows. Seeding rate 4kg/ha. Scarification increase germination. Fresh seeds have poor germination (better wait 3-12 months).

Seed treatment before planting: Treat the seed with lindane dust, 20% dust at 1 kg per 80 kg of seeds, if seed-harvesting ants are prevalent.

Minimum germination and quality required for sale: Buffle has poor germination.

Grazing: Buffle withstand considerable grazing once it is established.

Minimum germination required is 20% and 90% of purity.

Compatibility with other grass and legume: Buffle is often sown with Columbus grass *(Sorghum almum)*, with Rhodes grass and others but not with legumes (competition high from Buffle).

Ability to compete with weeds: rather good.

Suitability for hay: reasonably good hay if grass are collected in the early flowering stage.

Palatibility: It is very palatable when young and fairly palatable at maturity.

Toxicity: Observed to horses.

Value and potential: It is one of the best adapted grasses to semi-arid conditions. Resistant to trampling and to dry spells.

Limitations: Does not control erosion very well (plant structure). Does not grow well on heavy soils. Should not be used as ley pasture before cropping because difficult to remove for cultivation and its depressing effects on a following crop. Suitable to stabilize structures on forest and grazing lands, improve pastures and waste lands.

Chloris gayana

Common names: Rhodes grass

Description: a glabrous, usually stolonifereous perennial up to 90 cm high, but very variable, roots up to 4.7 m depth.

Rainfall requirements: 600-750 mm.

Drought tolerance: Good.

Soil requirements: Grow on a wide range of soils, prefers loose-textured loams. Tolerate temporary waterlogging.

Tolerance to salinity: Excellent

Ability to spread naturally: Excellent (produce stolons which creep over the ground and produce abundant seed.

Sowing method, seeding rate, sowing depth and cover: drilling seeds in rows, or broadcast, mixed with sawdust, on the surface or no deeper than 2 cm, and covered with a bush or a roller. Recommended seeding rate is 4g/ha.

Minimum germination and quality required for sale: 50-60% and 50% purity.

Grazing: It stands considerable grazing and defoliation. Better graze before flowering.

Seed treatment before planting: Treat the seed with lindane dust, 20% dust at 1 kg per 80 kg of seeds, if seed-harvesting ants are prevalent.

Compatibility with other grass and legume: Does grow with stylosanthes.

Ability to compete with weeds: Moderate, good after burning of scrub lands.

Suitability for hay: It makes quite good hay if cut just as it begins to flower or a little earlier. Old stands give low-quality hay.

Palatibility: Young growth is very palatable, but after plants have seeded they are less attractive.

Toxicity: None.

Value and potential: It can be used for pasture lay and stabilization of forest areas, not recommended along bunds near to cultivated fields. It is widely adaptable and easy to establish. Good erosion control.

Limitations: short season of nutritive peak in many cultivars.

Sorghum almum

Common name: Columbus grass

Description: It is a short-term perennial, tall, well above 2 m, producing short rhizomes, reaching a depth of 50 cm.

Rainfall requirements: 460-760 mm

Drought tolerance: moderate to good.

Soil requirements and tolerance to salinity: prefers soils with good fertility, from loams to heavy clays. Tolerates temporary waterlogging and is tolerant to salinity and sodicity.

Ability to spread naturally: slow

Sowing method, seeding rate, sowing depth and cover: Planted in rows or broadcasted at 2 cm depth on a fine seed bed. Roll or light harrow the field after sowing. Seeding rate 2-4kg/ha.

Seed treatment before planting: No dormancy. Treatment with fungicidal and insecticidal dust if necessary.

Minimum germination and quality required for sale: 70% germination and 90-100% purity.

Grazing

Compatibility with other grass and legume: some with *Cenchrus ciliaris* (Buffle) and *Chloris gayana* (Rhodes).

Ability to compete with weeds: rather good.

Suitability for hay: It gives quite a good, though coarse hay, which is useful during the dry season.

Palatability: Quite palatable, but not as readily eaten as annual sorghums.

Toxicity: Commonly to other *Sorghum* species, Columbus grass contains dhurrin, a cyanogenetic glucoside which can be toxic, particularly in plants carrying young shoots, either from the base or old stems.

Value and potential: It is quite valuable for erosion control on hillsides but needs N application to form an effective cover. It is also recommended for ley pastures and cropping, improve fallows and stabilize trenches constructed on good soils. It

Limitations: Does not like very high temperatures and prolonged periods of drought. It is also a difficult weed to eradicate in irrigated crops. It normally has a short life (2-4 years).

Panicum coloratum (var. makarikariense)

Common names: Makarikari

Description: It is an erect (1.5 m) perennial with robust culms and shortly rhizomatous, seldom stoloniferous.

Rainfall requirements: 500-1000 mm.

Drought tolerance: moderate.

Soil requirements and tolerance to salinity: Best performance in high fertility black clay soils. Very tolerant to waterlogging and to saline conditions.

Ability to spread naturally: slow (by seeds) and occasionally stolons.

Sowing method, seeding rate, sowing depth and cover: Prepare a good seed-bed. Drill seeds 1-1.5 cm deep in rows (30-90 cm apart) or broadcast, and roll afterwards.

Seed treatment before planting: Initial dormancy. The seed requires a ripening period of 6 months after harvest.

Minimum germination and quality required for sale: 20% germination and 80% purity. Scarify seeds.

Grazing: Withstand heavy grazing but should be lightly grazed the first year to encourage tiller development.

Compatibility with other grass and legume: low.

Ability to compete with weeds: low, require weeding at initial stage.

Suitability for hay: It makes good hay.

Palatibility: It is very palatable.

Toxicity: None.

Value and potential: May be useful in erosion control because of its large crown development. Good for mulching and stabilization of structures in heavy clays and waterlogged areas (add N fertilizer).

Limitations: Uneven seed set and seed shattering.

Panicum maximum var. trichloglume

Common names: Green panic.

Description: A tufted, tall (over 1 m) perennial with fine stems and leaves with a short creeping rhizome.

Rainfall requirements: 650-1700 mm

Drought tolerance: Moderate.

Soil requirements and tolerance to salinity: It does best on deep fertile loams but performs well in moderatly fertile sandy loams and black soils. Moderate tolerance to salinity (up to pH 8) and slight tolerance to waterlogging (few days only).

Ability to spread naturally: slow to moderate.

Sowing method, seeding rate, sowing depth and cover: A fine seed-bed is needed. Sowing is in rows (30-90 cm) or broadcasting, drill the seed at maximum 1 cm depth and cover lightly. A 4kg/ha seeding rate is recommended.

Seed treatment before planting: Dormancy is very long (18 months)

Minimum germination and quality required for sale: 20% germination and 70% purity.

Compatibility with other grass and legume: It is compatible with *buffle* but not with *rhodes*. It grows well with *siratro (Macroptilium Atroppurpureum)* legume.

Ability to compete with weeds: good.

Suitability for hay: It makes a good hay when cut at flowering stage.

Palatibility: Very good.

Toxicity: Rare.

Value and potential: Not very useful to control erosion (plant structure). Good for loamy sandy areas, for stabilization of structures and improved leys.

Limitations: Lack of persistence in poor soils without application of fertilizers.

LEGUMES (extracted from ***A guide to better pastures, for the tropics and subtropics, by L.R. Humphreys -1980)***

Styloshantes hamata

Common names : Verano stylo
Description: It is a short lived pernnial legume, which grows low and develop a flat crown under grazing, erect stems may grow 80 cm high under good conditions and can produce considerable amount of seeds (can yield up to 1 ton/ha) .
Rainfall requirements: 600-1200 mm
Drought tolerance: Good.
Soil requirements and tolerance to salinity: Grows on a wide range of soils but prefers well drained sandy soils of low fertility and do not stand well in cracking-clay soils and waterlogging. It is also rather alkaline and saline resistant.
Sowing method , seed rate ,sowing depth and cover: Stylo is easy to establish, oversowing at the surface after rough opening of the soil with implements. Row sowing is also possible with seeds drilled into rows, at 0.5-1 cm depth and covered lightly. 3-6 kg/ha is recommanded.
Seed treatment before planting : Not reqired except for fresh seeds (scarification in hot water -70°- for 10 minutes.
Minimum germination and quality required for sale: 20-40% germination and 96% purity.
Grazing: It tolerates heavy grazing and produces a lot of seed on branches close to ground in these circumstances.
Compatibility with other species: Can be a good companion crop with Buffle.
Ability to complete with weeds: Good in poor soils and pastures but in cultivated fields weeds compete with vigorously with stylo. In this case deep ploughing and harrowing before sowing stylo is necessary, particularly if stylo is to be used for ley cropping or improved fallows (see measures).
Suitabilty for hay: Makes good hay
Palatibility: Good
Toxicity: None
Value and potential: Easy to establish, restore ferility of poor soils and is one of the most popular conservation legumes.
Limitations: Does not tolerate shade

Macroptilium atropurpureum

*Common names:*Siratro
Description: It is a perennial legume with strong creeping stolons and broad leaves. It is short lived if heavily grazed.
Rainfall requirements: 750-1500
Drought tolerance: Good
Soil requirements and tolerance to salinity: It is a versatile legume and grows also well in shallow soils (hillside legume) but is not as low fertility tolerant as stylo and is not very tolerant to waterlogging.
Sowing method, seeding rate, sowing depth and cover: can be either drilled at 1-2 cm depth (seed rate 4 kg/ha) or broadcast (seed rate 6kg/ha) in well prepared seed bed.Phosphate applications at sowing time ensures an excellent establishment.

Seed treatment before planting: Seeds are hard and need scarification in hot water at 80°
for 10-15 minutes.
Minimum germination and quality required for sale: 70% min. germination and 97% purity.
Grazing: Moderate
Compatibility with other grass and legume: It combines well with Rhodes, Green panic and Buffle.
Ability to compete with weeds: Moderate to good
Subility for hay: Limited by the creeping structure of the plant
Palatibility: Good
Toxicity: None
Value and potential: Most important legume for its excellent nodulation and ability to restore fertility in shallow soils, and stand various associations with different grass for mixed pastures.
Limitations: Not suited to waterlogging and sodic areas.

Dolichos lablab

Common names: Lablab
Description: Short lived perennial or annual legume. It forms a vigorous, erect seedling which later develops long trailing stems. It has very large leaves.
Rainfall requirements: 500-1500
Drought tolerance: Good
Soil requirements and tolerance to salinity: Is suitedto a wide range of soils.
Sowing method, seeding rate, sowing depth and cover: Seeds are sown drilled at 1-2 cm depth after rough seed bed preparation, with seed rate 6 kg/ha in mixture with grass and 15-20kg/ha as sole legume.
Seed treatment before planting: None or light scarification. Inoculation is recommanded.
Minimum germination and quality required for sale: 75% germination and 97% purity.
Grazing: Good
*Compatibility with other grass and legume:*Good as cover crop and for improved fallows, ley cropping, green manuring with fodder crops (sorghum, millet)and few grass.
Ability to compete with weeds: Good as grazed fodder cropPoor.
Subility for hay: Poor
Palatibility: Good but cattle may take a little time to get used to the taste of lablab.
Toxicity: some bloat occasionally occurs when hungry animals graze lush vegetation. Otherwise none.
Value and potential: As good and even better than cowpea (*Vigna sinensis*) for green manuring and as a pioneer pasture legume,
Limitations: Under Dry Zone conditions is an annual.

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