DEVELOPMENT OF A TECHNOLOGICAL PACKAGE FOR SUSTAINABLE USE OF DAMBOS BY SMALL-SCALE FARMERS

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DEVELOPMENT OF A TECHNOLOGICAL PACKAGE FOR SUSTAINABLE USE OF DAMBOS BY SMALL-SCALE FARMERS

by

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Dedicated to Mum and Dad (Posthumously)

(Mugabi Dambo: Photo by A.E.Daka)

"Water resources, and the related ecosystems that provide and sustain them, are under threat from pollution, unsustainable use, land-use changes, climate change and many other forces. The link between these threats and poverty is clear, for it is the poor who are hit first and hardest."

Source: Ministerial Declaration, 2nd World Water Forum, The Hague, March 2000.

ABSTRACT

The sustainable use of Dambos for crop production using a technological package is presented. Dambos which are known as vleis in South Africa and Zimbabwe, fadamas in West Africa and mbugas in East Africa are identified as potential environments and key-resource areas for alleviating poverty and hunger in arid and semi-arid areas where drought occurrences are characteristic and limit upland crop production. Dambos present themselves as environments with soil moisture potential and high water tables ranging from 50 - 100 cm below the ground surface for most part of the year. Particular difficulties arise in abstracting this water for use to irrigate crops in Dambos. Most small-scale farmers use a rope and a bucket to draw water from hand dug wells. These methods are labour intensive and thus limited lands are cultivated by small-scale farmers.

This study has identified, modified and introduced a treadle pump as a technology for lifting water from shallow water tables such as in Dambos. The treadle pump also lifts water from rivers, swamps, wells and dams within a suction lift of 0-8 m to the intended place of use i.e. vegetable garden, domestic application, livestock watering and in construction. The study has further investigated and introduced the clay pot as a water saving device. The clay pot sub-surface irrigation technology saves between 50 and 70 % of water as compared to conventional watering can and bucket systems. This technology can combine well with the treadle pump by using the latter to refill water in the former, thus making it easy to fill the system once the water is depleted.

The use of the treadle pump has demonstrated its impact on the society in many ways. Firstly: the small-scale farmer is now able to increase the size of his/her garden from 0.1 ha irrigating using watering cans/buckets to between 0.25 ha and 0.5 ha using the treadle pump. With this innovative way of irrigating, farmers have thus been able to diversify cropping. Secondly: farmers have been able to increase household income from a meager US$125 without a treadle pump to US$850 and US$1700 on a 0.25 ha piece of land with a treadle pump on a 300% cropping intensity (growing crops three times a year). This has helped the country reduce on imported vegetables and thus save the much needed foreign exchange. Thirdly: the technology has contributed to employment creation, notably from the manufacturing point of view where artisans are employed to make the pump and carpenters to make the wooden parts. On the output side for buyers (merchants/hawkers) and transport contractors who trade and transport the produce.

The study essentially alludes to the great impact the treadle pump has made by noting the brand naming of the pump as ‘Chova pump’ by the small-scale farmers. Chova is a local name, which means to boost one’s income or to pedal signifying the manner in which the pump is operated. Dambos, cover about 3.6 million hectares of land in Zambia and are suitable environments for application of the treadle pump. The potentials and limitations of Dambos are highlighted and the impact of their use using treadle pumps elucidated. Marketing of Dambo produce is discussed with respect to the adoption of the technology. The study notes that Dambos are highly accessible with no land tenure limitations. Thus the more than 800,000 small-scale farmers in Zambia have an opportunity to utilize Dambos for crop production and help reduce poverty and food insecurity at household level.

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I would like to thank the International Foundation of Science for awarding me a Research Grant from 1992 to 1997 to study Dambos indepth. It is from this work that the hydro-dynamic evolution of water tables, the movement of water and its fate in Dambos became clear from a technical point of view.

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Angel Elias Daka

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CHAPTER 1
INTRODUCTION

1.1 Background on Zambia

Zambia's population is currently about 10.3 million people (C.P.H, 2001). According to the Census of Population and Housing (C.P.H), it stood at 5.8 million in 1980 which was 40% higher than that recorded in 1969 (CPH, 1981). This indicated an average annual population increase at the rate of 3.1%. By 1990, Zambia's population was 7.8 million and the annual growth rate was about 3.2% (CPH, 1990). At this growth rate, the population in 2001 is estimated to be 10.55 million. This is a rapid population growth rate. About 72.9% of Zambia's population lives in poverty due to insufficient food resources and poor socio-economic conditions. The Government's objective is to reduce this poverty level to 50% by the year 2004. This is quite challenging considering that the country is one of the poorest in the region and is currently undergoing massive economic structural adjustment programmes which entail a lot of suffering particularly for the poorest in society.

"Within the SADC (Southern African Development Community) region, the current population of about 84 million is growing at a rate of approximately 3% per annum. Many people in the region have experienced a decline or stagnation in living standards since 1980. Significant increases in agricultural food productivity will be required to improve food security and quality of life"(World Bank, 1994).

The ever-increasing population of Zambia calls for immediate action towards improving agricultural food production because of the mounting pressure on the food and fibre requirements. The 2.7% annual growth rate of Zambia's agricultural food and fibre production has not matched the population growth rate in recent years (NAP, 1995).

Adverse climatic conditions entailing persistent drought years have had ripple effects on rain fed agriculture which is a mainstay of over eighty percent of the estimated one million Zambian farmers. Due to this phenomenon, there has been a clear shift to utilize Dambos, which remain wet even during severe droughts. Increasing population is escalating the socio-economic pressure to expand the extent to which Dambos are utilized for agriculture.

In Zambia, Dambos have been utilized to bridge the hunger gap when food resources ran out at household level by extending food production into the dry season.

Accordingly, the country faces chronic food deficits in coming years unless positive counter measures are taken to reverse the trends. The decontrol of prices and liberalization of marketing in which the government has withdrawn from direct marketing and became a facilitator has also not been dynamic. The removal of subsidies on agricultural inputs has left small-scale farmers with no capacity to expand cultivation of their land. The system has had poor financing and storage arrangements and flow of marketing information to the extent that arbitrage has emerged. Thus, the marketing system also requires re-orientation.

1.1.1 What is a Dambo?

Daka (1995) describes a Dambo as a wide low lying concave gently sloping treeless grass-covered depression which is seasonally waterlogged by seepage from surrounding high ground assisted by rainfall. It derives its fertility from accumulation of organic matter in this depositional sink of soil nutrients and it exhibits water tables for most part of the year in the upper 50 - 100 cm of the soil profile from which they drain into streams.

This definition seems to accord with hydrological, vegetational and ecological aspects of most Dambos. It is evident that the hydrological aspects of Dambos are the ones that have drawn attention of most farmers, ecotourists, environmentalists and researchers although not much work has been done in this respect. Various definitions for Dambos have been

suggested (Mharapara, 1995; Raussen *et al*, 1996; Ferreira, 1981; Huckaby, 1986; Verboom, 1970) to mention but a few. E.C.Z (1994) quotes the Ramsar Convention to define wetlands of which Dambos are part of as " areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary with water that is static or flowing fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters".

Breen et al. (1997**)** refers to Dambos as shallow, seasonally or permanently waterlogged depressions at or near the head of a drainage network, or alternatively, may occur independently of a drainage system.

1.2 Natural Resources of Zambia

1.2.1 Climate

Variation in altitude, latitude, temperature, relative humidity, radiation distribution and the control of air masses, largely governed by the influence of the Intertropical Convergence Zone (ITCZ), causes differences in rainfall distribution of the country.

The mean annual rainfall ranges from 650 mm in the south to about 1500 mm in the north, falling mainly between October and April. Rainfall totals and intra-seasonal distribution vary greatly from year to year, particularly in the south.

Zambia's rainfall pattern is very undependable especially in agro-ecological Regions I and II where annual totals range from 400 - 800 mm and 800 - 1000 mm respectively with a highly variable distribution in time and space. Conversely, agro-ecological Region III is a high rainfall area with dependable annual total rainfall of 1000 mm - 1500 mm with characteristic perennial rivers and wet Dambos.

Figure 1 shows an agro-ecological map of Zambia.

Temperatures generally vary from 14^o C to 30^o C. July is the coldest month with average temperatures of 16^o C. Night air-frost may be recorded in May, June, July and August particularly in central and western areas of the country. October is the hottest month with mean daily maximum temperatures reaching 30^o C. The plateau areas generally experience cooler temperatures because of high altitude. Figure 2 illustrates variations in rainfall and temperature distribution in Senanga district of the western province of Zambia.

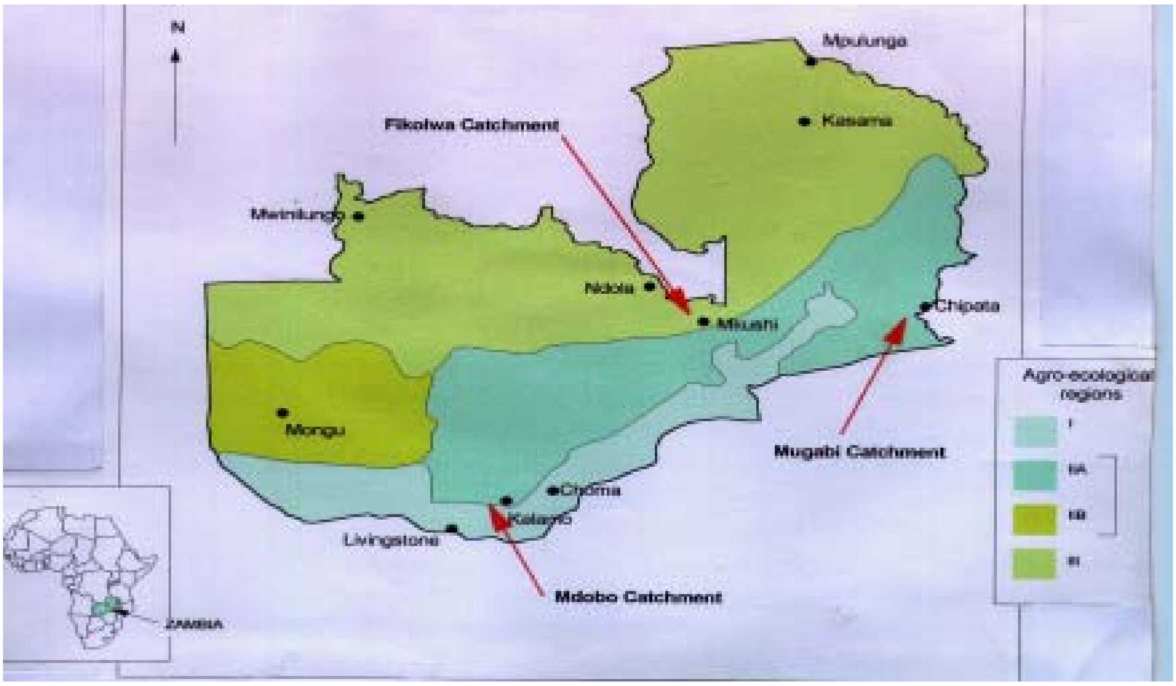


Figure 1: Agro-ecological map of Zambia.

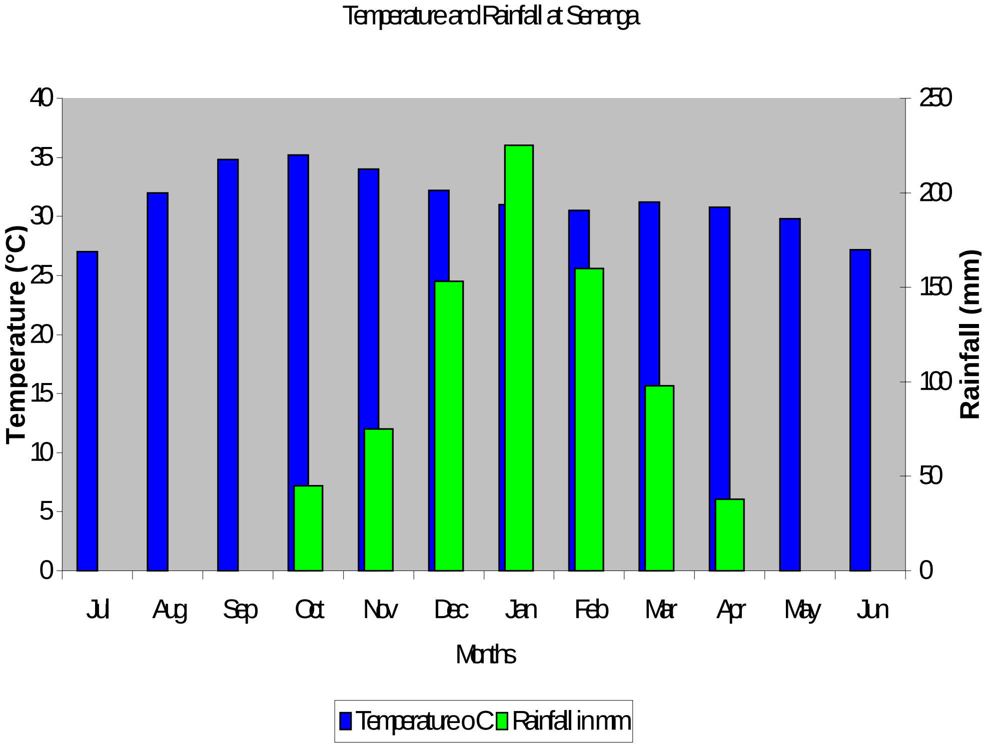


Figure 2: **Graphic presentation of the early summer drought hazard (6 years average)**

1.2.2 Land Resources

Zambia's main natural resource is land which covers about 75.3 million hectares of which 920,000 hectares are covered by water bodies such as: lakes, swamps, and rivers. NAP(1995) estimates that about 18 million hectares (24% of the country) are arable, of which only about 11% is cultivated annually.

Food and fibre production under irrigation covers about 150,000 hectares of which 100,000 hectares comes from small-scale farmers cultivating vegetables in Dambos/riverines using buckets for irrigation and the remaining 50,000 hectares representing medium to commercial irrigation farmers who use different intermediate to high technology irrigation systems. The major farming activity is essentially from small-scale upland rain fed agriculture which is undependable due to poor rainfall distribution and amounts.

1.2.2.1 Soils

The country's upland soils are essentially of "low inherent fertility". Most of these soils are moderately leached sandveldts, loams and clays. Their texture and structure vary considerably and hence their physical properties. However, the soils occurring in most Dambo areas are characterized by a dark colour in the top 30 cm of the soil profile. In more cases than not the layer is covered by silt loams underlain by silt clay loam with clay developing in deeper layers. Clay appears to have eluviated to lower horizons into water tables. Black colour is chiefly on account of their high organic matter content (humus). Dambo soils have supported crop production on a sustainable basis for several decades without having to apply external inorganic fertilizers on account of their organic matter and high nutrient pool. There is currently an increasing trend to Dambo cultivation due to their wetness and high fertility status for crop production. The variation in soil fertility status of both upland and lowland Dambo soils has to be viewed and approached cautiously with different land management practices applied if production is to be sustainable.

Sustainability in food production would entail continuity of food production given that all limiting factors are mitigated. In agriculture, many factors contribute to proper and increased food production. Such factors include land in its broadest sense (soil, water, climate and vegetation), financial and human resources.

It is understood that given all factors except water are present in abundance, food production is however not possible in the absence of water - one of the components of land resources. Sustainability implies that economic motivation and maintenance of land resources encourages the farmer to produce on a continuing basis and that his work allows him to improve his standard of living.

1.2.2.2 Vegetation

White (1962) documented forest flora for Zambia whilst Burtts (1953 and 1957) derived a field key for the identification of miombo trees. Useful trees for Zambia have been characterized by Fanshawe (1972) and his findings are alluded to by Storrs (1979). Comprehensive accounts of species and vegetation types are given by Fanshawe (1969) while ecological studies have been conducted and described by Lawton (1978). Dambo watershed areas are mainly covered by miombo woodlands which are susceptible to strong bush fires. Miombo woodlands are also called *Brachystegia-Jubernardia* wood (Chidumayo, 1993). Other common species include *Isoberlinia angolensis* and *Marquesia macroura*.

The Dambo margins in most areas are surrounded by *Uapaca* spp which are sources of wild fruits. The ground level vegetation consists of *Hyparrhenia* grasses which are frequent and according to Fanshawe (1969) and Lawton (1978) grass fires occur during the dry season (May - October). In the Dambo proper and the central part of it, many grass species and herbaceous plants are a characteristic. Typical plants are *Loudetia*, *cyperus*, *monocymbium*, *Loxodera* and *Mischantidium* (Ferreira, 1981). Besides grasses and sedges, pink flowered *Dissotis* spp are characteristic. Fanshawe (1969) further describes Dambo vegetation as moderately dense mat of grass, sedges, herbs and shrubs 50-70 cm high with flowering culms. Some streams associated with Dambos are mostly covered by mushitu vegetation (*Syzygium cordatum*) and *Gardenia imperalis* as typical vegetation.

1.2.2.3 Water Resources

A resource is not, it becomes. Until a material becomes relevant to some functional use, it is never a resource. Water is a great resource to our daily lives. It is useful to agriculture, industries, construction works etc. Unfortunately, Zambia has not fully tapped both the water and soil resources for agricultural food production. Zambia is among one of the very few countries in Africa that are blessed with abundant water resources accounting for about

45% of southern Africa's water resources (MAFF, 2000).

There are also large tracts of soils that are suitable for irrigation. Zambia is endowed with 114 billion m^3 of water from both groundwater and surface source. The former constitutes

96 billion m^3 whereas the latter comprises 18 billion m^3 mostly of good quality water for agricultural purposes (Daka, 1986). Small-scale farmers have access to surface water from rivers, Dambos, swamps and dams/shallow wells. Vegetable production is possible throughout the year in Zambia as there are sources of water for irrigation and this provides food for most households. The drainage system for the country is shown in Figure 3.

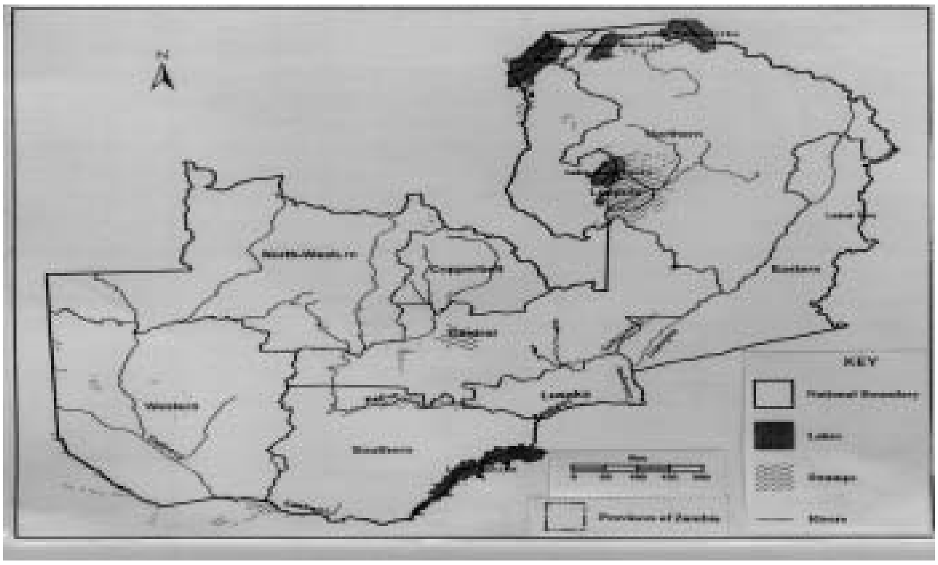


Figure 3: The drainage system for Zambia's water resources.

1.3 Dambo Use and Access for Utilization

Because of increasing populations and decreasing food production in dryland rain fed farming as a result of severe droughts, there has been an increasing trend to use Dambos for crop production in recent years. This is mainly because Dambos are highly fertile and support crop production even in the dry season because of their moisture retention potential.

Dambos are also used for grazing animals in the dry season when upland vegetation is dry with little or no supporting nutrients. In Luapula province, the high population density in the valley areas is a result of people moving from unproductive upland areas to highly fertile and productive Dambos.

Dambos cannot be described today as Dougnac (1999) did indicate that they are “largely unutilized” or very little utilized for agricultural production particularly in Luapula province. This is a misconception considering the increased emphasis on cash and food crop diversification in Mansa, Mwense and Kawambwa districts in the province. Whilst Dambos have been highly utilized for several years in Eastern, Central and Western provinces of Zambia, giving over thirty years of sustainable utilization and indigenous knowledge to cope with flooding in them, there had been a lag-time in wide utilization in Luapula province until early 1990's due to inadequate knowledge to cope with flooding, cultivation of heavy soils and soil acidity which suppressed establishment of most crops. Extreme drought years after this period has forced farmers to adopt practices which counter these associated problems, such as in Eastern province where Dambos are extensively used for agricultural production. Such strategies are discussed in subsequent chapters of this thesis. Another reason accounting to the under-utilization of Dambos in Luapula province during that period, is fishing which is very profitable and is a major occupation of small-scale farmers in the province.

Malnutrition levels being very high in the province and the prevalence of hunger during the dry season, justifies the present adoption of dry season exploitation of Dambos for fishing and vegetable production. Long-term trials by the Adaptive Research Planning Team culminated in the introduction and adaptation of vegetable crops in Dambos of Mabumba in Mansa district, Mubende and Lubunda in Mwense district. However, one factor comes into play when considering Dambo cultivation adoption in Luapula province, i.e. the issuing of free inputs to farmers during trials discouraged continuity without free inputs after trials were concluded. This phase has passed and today there are over one hundred and fifty small-scale farmers using treadle pumps to cultivate upper grassland zones of Dambos to produce vegetables. The FAO has initiated a Luapula Livelihood Food Security Programme and is involved in the promotion of horticultural crop production using the treadle pump technology in Dambos.

Dambos are highly accessible and by virtue of being scattered all over, they play an important role in mitigating problems of food insecurity as the majority of small-scale farmers have access to them without legal processes of acquisition.

Land tenure issues are addressed by chiefs or headmen and land so acquired can be passed to the next of kin. Usually the land rights in Dambos can be described as informal and accommodating particularly because no written contracts are required and other immigrant tribes are allowed access to Dambo land as long as they accept to observe the local customary laws respectfully. No legislation currently exists to restrict exploitation of Dambos in Zambia. However, deliberate efforts for their sustainable use is encouraged through community awareness campaigns on proper land use practices and management of their watersheds.

1.3.1 Potential Uses of Dambos

While forming part of a larger set of wetland habitat, Dambos have certain characteristics which place them apart from environments such as alluvial valleys and justify their study as a separate resource (Adams and Carter, 1987).

Dambos play an important role in the livelihood and food security of most rural people in Zambia. Significant contributions are observed in crop, fish and, to a minor extent animal production (grazing/hunting small animals). This significant role is more prominent in Luapula and Western provinces than other areas. Other livelihood options to the people with access to Dambos are irrigated cropping, supply of water for livestock and domestic purposes, collection of wild foods, soaking of cassava for processing, hunting of small animals, building products such as grass for thatching and reeds for making mats and collection of various coloured soils for moulding of bricks and decorating houses (see Figure 4).

Figure 4: Moulding bricks from Dambo soils for construction purposes.

For several decades farmers in Zambia like those in floodplains of Egypt, Senegal, Niger and along the Zambezi have followed a risk spreading strategy to grow crops in Dambos. Crops planted at different times of the year and at different elevations or zones of a Dambo floodplain eg. Litongo or Sitapa gardens ensure that some escape flooding and others escape drought. A variety of crops ripening at different times cope with differences in annual flooding patterns ensuring a constant food supply.

MAWD/FAO (1986) in proceedings for a National Workshop on Dambos notes that crops grown in Dambos of Zambia have included vegetables grown on ridges and high flat beds, rice, wheat, maize and other cereals while grazing of cattle has been a major activity since 1920's. The report, however, notes that there are different types of Dambos which support various utilization types and thus data and conclusions from one cannot be generalized for all Dambos. It is, however, observed that despite having variable definitions of Dambos, a holistic approach to the classification of Dambos should include technical aspects of hydrology, physiography, climate and soil.

Zambia needs to boost food production through expanded irrigated land area as it possesses a tremendous potential on account of its vast water resources both from rivers and underground.

The expansion programme could be achieved by encouraging small-scale farmers, who comprise about 80% of the Zambian farming community, to practice irrigation and extend the growing season through to the dry season. Such possibilities include a deliberate promotion of Dambo use for irrigation provided associated constraints are uplifted.

A more sustainable solution is to encourage low-cost irrigation technologies for rural applications and explore possibilities for manufacturing such technological equipment locally. Examples of such successes include the use of low lift and low-cost water lifting devices like the treadle pump and the clay pot sub-surface irrigation technologies which have been applied successfully elsewhere in Burkina Faso, Bangladesh, Brazil, India, Iran and Malaysia. Development and transfer of these technologies would promote utilizing the existing potential as a vehicle to increasing the food and fibre production to levels that would match the high food and fibre demands of the population of Zambia.

1.4 The Problem and Approach to the Solution

This thesis highlights crop production constraints in Dambos and the development of a technological package based on farmers' perceived solutions to uplift the major constraints inhibiting increased food production. Fundamentally, the subject deals with understanding the Dambo hydrology and recharge mechanisms in order to derive an appropriate technology for sustainable utilization.

Land utilization in Dambos has been viewed both as a curse and a blessing on account of periodic and sometimes permanent flooding and drying over the growing season. Farmers have over time developed indigenous methods of coping with peculiar difficulties related to flooding and receding of water tables in extreme dry years. Such coping strategies entail the use of a rope and bucket to draw water from receding water tables in hand dug wells and growing crops on raised beds and ridges to avoid flooding. The study aims at using farmers indigenous knowledge to develop a feasible technological package for proper and sustainable land use in Dambos.

1.4.1 Dambos as resource areas

Dambos have been recognized as key-resource areas worth exploiting agriculturally by small-scale farmers for several decades. This has thus attracted attention of many people such as agriculturalists, eco-tourists, hydrologists, ecologists etc. on account of their soil moisture and water potential.

Dambos exist in other parts of Africa and are known by different names such as: Vleis in South Africa and Zimbabwe, Mbugas in East Africa and Fadamas in West Africa. An estimated total of 240 million ha of wetlands exist in tropical Sub-saharan Africa which include: coastal wetlands, river floodplains, inland valleys and Dambos (Andriesse, 1986). The distribution of Dambos in Southern Africa is represented in Figure 5.

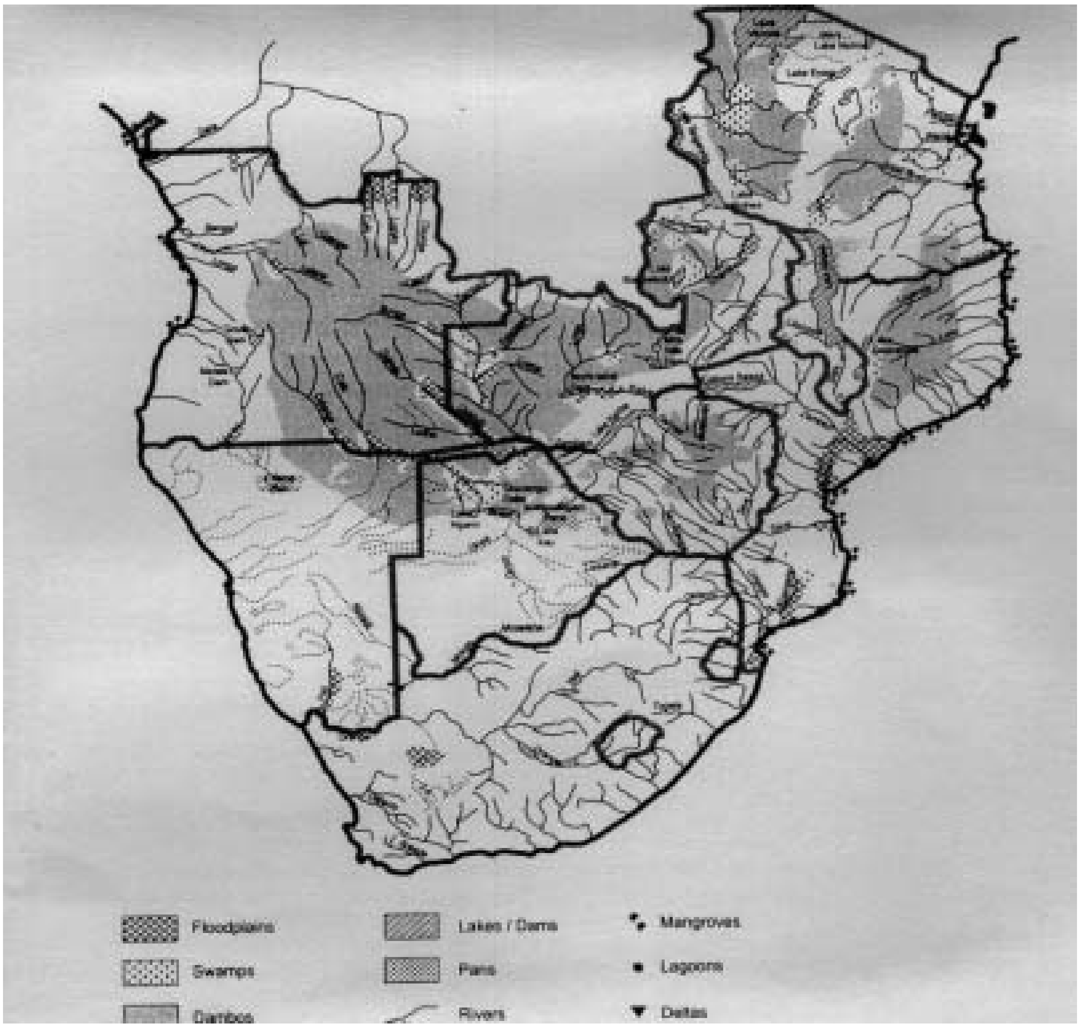


Figure 5: **The distribution of Dambos in southern Africa.**

Flying in mid dry season over southern parts of Africa, one recognizes what Wien (1995) describes as green islands surrounded by brown sea: moist, green, patchy wetlands, called Dambos, in the dry, brown Savannah (Raussen and Daka, 1999). These Dambos are special ecosystem natural resources as they have been utilized by many rural people to provide for their livelihoods.

The residual moisture of the Dambos is very important in regions with unimodal rainfall (6 - 8 months of dry season) and frequent droughts that reduce or lead to total failure of crop yields from rain fed upland fields. By cropping in Dambos small-scale farmers who usually don't have access to any formal irrigation, can extend the growing season for crops and vegetables in particular, to nearly the whole year. Dambo cropping in the dry season is based on residual moisture and hand irrigation from shallow wells. Irrigated Dambo cropping provides rural communities with cereals, tubers, fruits, vegetables and cash income.

In drought years production from Dambos is a vital safety net (Lovell *et al*., 1995) often providing the only source of food. Dambo cropping has the potential to increase the diversity of foods available and to smoothen out seasonal fluctuations in quantity and quality of foods McEwen (1993).

During most of the dry season upland pastures provide fodder of low quality. The diet of the livestock is significantly enriched by fodder from the Dambos where the herbaceous vegetation continues to grow throughout most of the dry season.

It is however important to understand Dambo use as part of the whole livelihood systems of small-scale farmers. Usually extension of one type of Dambo use competes with other uses. For example cattle grazing may damage vegetable gardens in Dambos.

Considering the importance of water for crop production in drylands, this work gives an overview on hydrology and irrigation aspects of Dambos using a developed water lifting technological device (treadle pump) to enhance crop production for household food security. The thesis recognizes and argues that although degradation of Dambos is not uncommon, with careful and appropriate use, irrigated cropping in Dambos has an enormous potential for sustaining livelihoods of farmers throughout Southern Africa.

This study has characterized natural hydrological phenomena of Dambos in three contrasting agro-ecological regions I, II and III with varying annual rainfall totals. Empirical evidence points to the fact that rainfall is of paramount importance in recharging Dambos. Soil fertility maintainance is discussed. Crop production constraints in different zones of Dambos are elucidated both from the standpoint of farmers and hydrology and vegetation in Dambos.

Use of a developed treadle pump technology and its socio-economic impact on rural small-scale farmers utilizing Dambos is discussed. The clay pot sub-irrigation has been introduced as a water saving technology as is presented in chapter 7.

The study has recognized that Dambos differ from one another and within themselves in terms of soil and chemical composition. The soil and chemical composition in most cases determine the fertility of most Dambo soils. Most farmers utilizing Dambos for crop production perceive Dambo soil to be highly fertile when it attains a black colour. Such soils usually show a presence of high organic matter in the top 30 cm layer.

However, decomposition of crop residues is seen to be poor in saturated zones of Dambos on account of poor aeration. The use of animal manure by virtually all farmers cultivating Dambos is a positive sign of sustaining soil fertility for considerable periods as has been seen in Zambia where no fertility loss beyond threshold levels of meaningful production has been observed for over thirty years of Dambo use.

Dambos are generally classified into different zones as described by Rattray *et al* (1953) and alluded to by Daka (1995) i.e Dambo margin, upper grassland, transition/seepage zone, lower grassland and the central Dambo zone (see Figure 6).

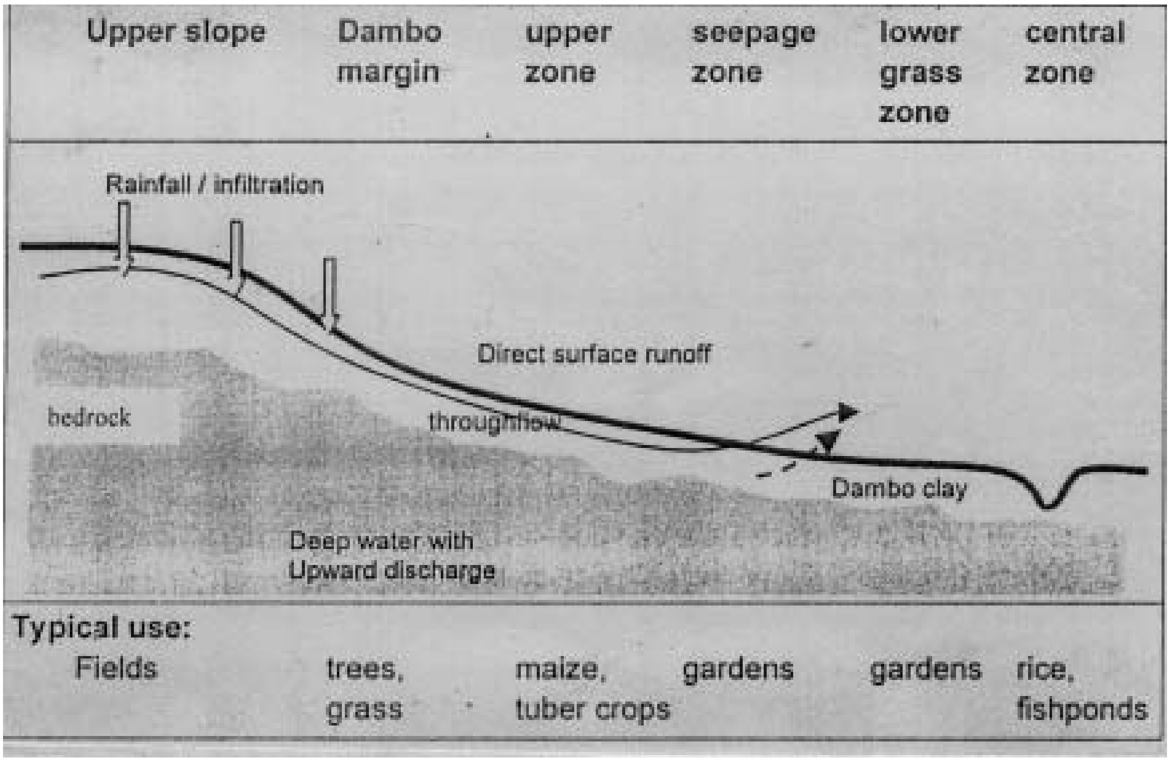


Figure 6: Delineation of Dambos into soil-moisture zones.

They are heavily affected by changes in rainfall variability over years. Farmers using Dambos have often confirmed that a good rain season was characterized by generally high water tables throughout the year.

On the other hand, a drought year which is characterized by excessive evapotranspiration has adverse effects of early drying up of Dambos in the dry season resulting in a general lack of water and farmers opting to re-deepen their sources of water (hand dug wells) in order to get water for both vegetable irrigation in Dambos and domestic purposes by using a bucket tied to a rope. The drying of Dambos also has ripple effects on the availability of pasture for grazing livestock.

In most cases Dambos form drainage lines and discharge excess water into streams and rivers which get recharged mainly by rainfall and to a minor extent by Dambos themselves. Some ephemeral streams and rivers continue to flow for some time in the dry season if Dambos have had a good rainfall recharge.

The presence of adequate moisture in the transition/seepage zone long after streams have dried out indicates that water is stored in the upper catchment aquifer of most Dambos. Recharge is promoted if the Dambo is characterized by sandy soils in the upper slopes where infiltration rather than rainfall run-off takes place. Water table variation in sympathy with rainfall input suggests that precipitation is a major contributor of Dambo recharge above all other recharge mechanisms. This study alludes to this fact by empirical evidence and is discussed elsewhere in subsequent chapters of this thesis.

1.4.2 Dambo Genesis

Two hypotheses for the genesis of Dambos have been developed and are summarized below. Different authors have looked at the development of Dambos from various perspectives as described in subsequent sections.

1.4.2.1 Dambos as result of fluviatile excavation, surface flows and sedimentation.

Dambos are the remains of ancient fluviatile valley systems that have filled with smectitic and kaolinitic clays through sedimentary deposition. The deposition led to a progressively weakening of the fluviatile energy to an extent that many Dambos are streamless today.

1.4.2.2 Dambos as result of landsurface incision, subsurface water flows and neoformed clays

Analysis of Dambo configuration in Malawi shows that these Dambos cannot be the result of fluviatile excavation. Dambos occur where differential leaching and landsurface collapses are geologically facilitated. The sizes of the Dambo areas depend on the extent of the incision processes and the groundwater tables. Dambos may therefore be considered a relatively recent incision in ancient landsurface and are under the influence of contemporary groundwater levels and movements (McFarlane, 1995). According to McFarlane (1995) and Bullock (1995) surface water plays a minor role in Dambo hydrology.

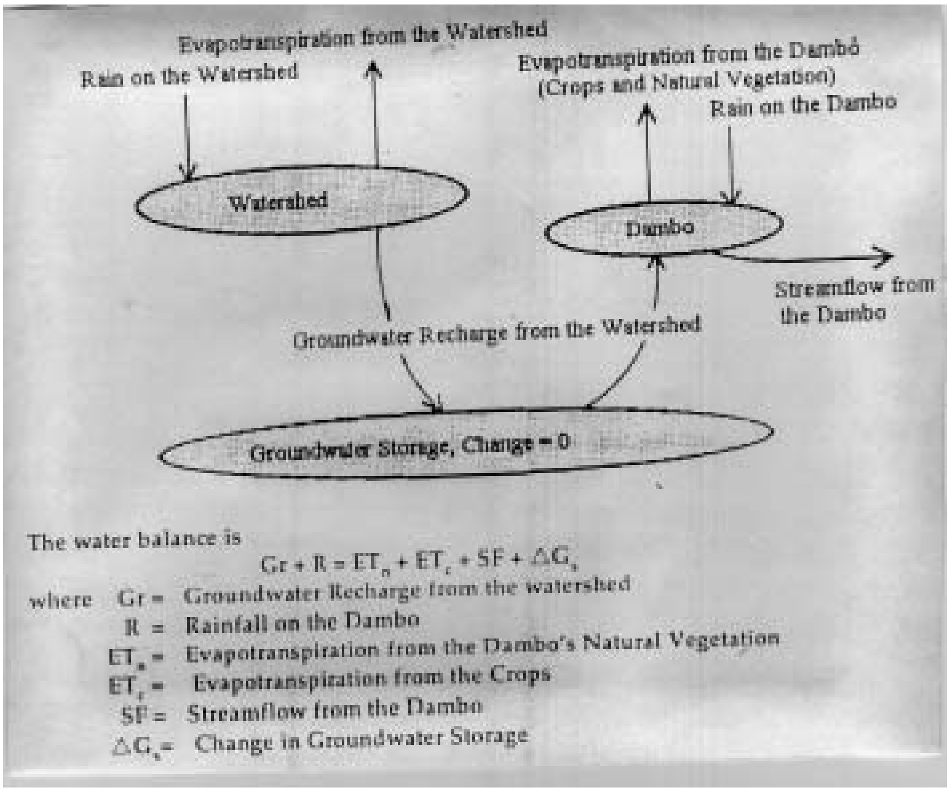
The dominantly smectitic clays in Dambos are unlikely to be sediments since smectite is not found on the catchments. There is some evidence that the smectitic clays in the Dambos are neoformed, as alumino-silicate evaporites from groundwater discharging into Dambos (McFarlane, 1995). This view is supported by Daka (1992) who saw evidence of alumino-silicates as parent material in the Dambos that he investigated in this study.

Due to the limited study area on which the second hypothesis is based, it is not clear whether the first hypothesis has to be reviewed by the more recently developed second one or whether the genesis of Dambos differs over regions and eventually between types of Dambos.

1.4.3 The Dambo watershed water regime

The variations regarding soils and water regimes between Dambos and even within a Dambo are common features (Giesen and Steenhuis, 1995; Lovell *et al.*, 1995; Mharapara, 1995; Bullock, 1995; McFarlane, 1995). However, recent studies agree on some hydrological principles that command the Dambo water regime.

Many studies (Kokwe and Daka, 1996; Raussen *et al*., 1996; Andreini *et al.*, 1995; Bullock, 1995; McFarlane, 1995) stress the importance to examine the hydrology of Dambos in the context of the interrelated components of the watershed Dambo stream flow system as indicated in Figure 7. The figure shows that the Dambo water balance is determined by rainfall, evapotranspiration and subsurface water flows.



The water balance is

$$Gr + R = ET_n + ET_c + SF + \Delta G_s$$

where Gr = Groundwater Recharge from the watershed
R = Rainfall on the Dambo
ET_n = Evapotranspiration from the Dambo's Natural Vegetation
ET_c = Evapotranspiration from the Crops
SF = Streamflow from the Dambo
ΔG_s = Change in Groundwater Storage

Figure 7: **Factors involved in determining water balances in a Dambo.**

1.4.3.1 The Dambo downstream water regime.

From the lower end of the central Dambo zone, usually a stream emerges into which excess water is discharged. Like in the case of Dambo genesis, the role of Dambos for the stream flow is unclear. The common belief is that Dambo clays overlying sandy layers regulate stream flow in a sponge-like fashion, absorbing water from precipitation by infiltration and slowly discharging it into the stream system. Consequently Dambos would have an important hydrological regulatory function (Dugan, 1994). Other authors (McFarlane, 1995; Bullock, 1995) question the sponge effect that is attributed to Dambos.

Smectitic soils, e.g. Vertisols, which are the most prominent Dambo soils, swell and shrink in response to variation in moisture content in the soil profile. On saturation with water these clays expand and swell tight and so become incapable of slow gravity feed to the stream system. After this, almost all water is lost through surface runoff (overland flow).

Except for the first rains in the season that sink into the cracks of the dry clay and later some retardation of surface flow by the grasses growing in the Dambo, there is no regulatory effect of Dambos on stream flow. This view is supported by recent research from Bullock (1995) who compared water flows from 110 catchments in Zimbabwe, which were still in a natural condition. He found that there is neither a significant influence of Dambo density in the respective catchment on the annual run-off nor on the variability of the annual flow. He concludes that Dambos are a minor factor in determining base flow and dry season flow at national scale in Zimbabwe.

Similar observations are reported by Du Toit (1985) from Zambia. Both authors find that with increasing deforestation of the catchments, both flood and dry season streamflow rise. This is attributed mainly to reduced evapotranspiration (Bullock, 1995) by the shallow rooted crops as compared to the previous perennial forest cover in the catchment.

While there seems to be some good evidence that Dambos play a minor role for downstream water flows, the question requires further hydrological studies over more regions and at various scales before final conclusions can be drawn.

Considering the practical implications of this debate on the sustainability of Dambo use and especially dry season flow of streams and rivers, hydrological research in Dambos needs to be given high priority. This is addressed by this study.

In Zimbabwe a legislation banning the use of Dambos exists for fear of possible dangers of drying these environments. In Zambia, no such legislation exists and farmers have used

Dambos for over thirty years without any seeming dangers of them drying up. What needs to be understood is under what circumstances these Dambos have been used, the problems and strengths of their continued use according to farmers' understanding and the possibilities for making improvements. Daka (1993) reported on variations of wetness intensities in different zones of some Dambos and how these could be used for crop production and elucidated that Dambo hydrology is mainly influenced by climatic conditions (i.e. rainfall, temperature and evapotranspiration), vegetation and soil water storage as affected by different soil types in different Dambo zones. Because of the nature of Dambo shapes which are typified by shallow linear concave depressions on the plateaux, water runs off from higher ground and also infiltrates into the soil and flows laterally in the sub-surface horizons and seeps to the central zone where it drains to the streams. Water typically seeps out onto the surface at so-called "seepage lines" which form at the contact between upper-slope sandier soils and clay soils on lower slopes. This characteristic was observed in all Dambos that he investigated. Dambos thus become seasonally or permanently waterlogged. Farmers have used *Syzygium cordatum* (Musinyika tree) and fig trees as indicators of the presence of water in a particular Dambo zone. In South Africa the "fever" tree (*Acacia xantiphloea*) is the typical indicator of the wet vertic clays in vleis along the Natal coast and in the Lowveld. This tree is also found in Dambos in Zambia and has mainly been used as an indicator of soil fertility.

1.5 Literature Review of Dambo Research

Hydrological and crop production studies for Dambos in Zambia and Africa as a whole are not exacting. From what is documented, many workers on Dambo research have looked at ecological and vegetational issues. Fanshawe (1969) characterized vegetation types in Dambos.

Although no comprehensive surveys have been done, several general accounts of Dambo vegetation exist (Rattray and Fitt, 1977; Rattray, 1957 and 1961; Boughey, 1961; Vincent and Thomas, 1961; Ivy and Bremley, 1972; Ivy, 1981; Mc Garvie, 1977; Kurima, 1981; Whitlow, 1980 and 1985a).

On the other hand Mackel (1974) elucidated the morphodynamics of Dambos in Zambia. Pedogenesis in Dambo soils has been studied in Zimbabwe (Savory, 1965). The process of weathering and dynamics of lateral clay translocation have been examined (Bond, 1963; Purves, 1975 and 1976; Thompson, 1965; Thompson and Purves, 1978; Fullstone, Godwin and Wells, 1981).

In Malawi McFarlane (1995) found that at the margin of Dambos there is often a wedge of clay, which extends upslope below a layer of sand. This clay wedge splits the water which moves laterally towards the Dambo into two distinct components as shallow throughflow moving over the clay wedge and sub-surface deep water passing below the clay wedge. Daka (1998) alludes to this principle and further argues that some of this water which discharges upwards into the Dambo is predominantly at or near the seepage zone (see Figure 8) where the Dambo clay is thinner and can be breached.

Other fractions of the deep water move below the Dambo clay towards the central zone where the clay comprises a tight lid, which prevents upward movement, deflecting the potential discharge downstream below the Dambo floor and may form a stream or river into which excess water is discharged. This principle forms the basis of the definition adopted in this study.

The throughflow and the deep water have distinct chemical characteristics, being rich in bases and silica for the latter and containing aluminum and other elements released in the most advanced stages of weathering for the former (McFarlane, 1995). The presence of nutrient rich springs in the Dambos seepage zone is confirmed by Kokwe (1991 and 1993).

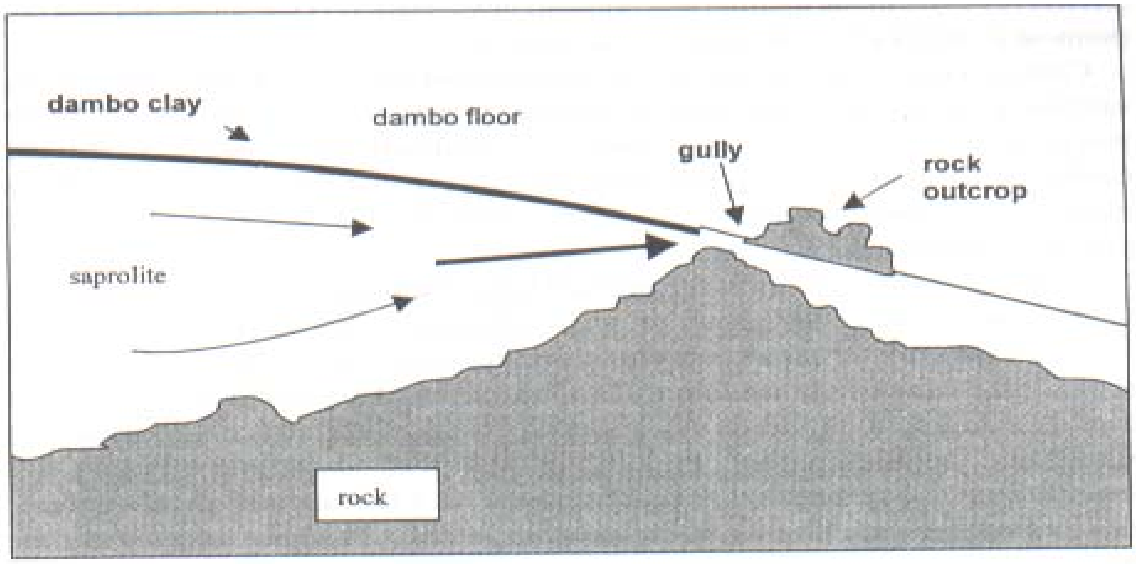


Figure 8: **Water movement and breaching of clay to effect gully erosion in Dambos.**

1.5.1 Hydrology and Crop Production

The only documented hydrological studies which dealt with the effects of rainfall in Dambos are those of Balek and Perry (1973) and Muneka and Mwassile (1986). A general study depicting the use of Dambos in Zambia has been initiated (Kokwe, 1991). In Zimbabwe, similar works were done to explain the use of Dambos in rural development (Loughborough University and University of Zimbabwe, 1987). Gosnell (1962) made a review of Vleiland (Dambo) development in west Kenya.

Some researchers have attempted to define Dambos because they are grossly misunderstood due to their complexity in nature. In all these studies, the accounts were rather generalized and using non-farmer participative approaches. The main hydrological processes are: Most rainfall on the watershed infiltrates and flows laterally underground over an impermeable substratum towards the lower lying Dambo areas (McFarlane, 1995; Raussen, Daka and Bangwe, 1996; Mharapara, 1995; Andreini *et al*, 1995; Bullock, 1995). This subsurface water may emerge in the Dambos seepage zone but often remains below ground because the clay soils of most Dambos act as an impermeable lid over the groundwater (Bullock, 1995; McFarlane, 1995). Rainfall directly on the Dambo area adds to the subsurface storage.

According to Daka (1996), most upland Dambos in Zambia show attributes of wetness either on temporal or permanent basis but significantly, all have shallow water tables. For example, some of Luapula and Northern provinces' Dambos are apparently endowed with perennial streams and are themselves usually wet though drying of Dambos due to long-term changes in rainfall patterns is observed. The drying is chiefly because of gradually reduced rainfall over the past ten years which has resulted into serious drought years in the Southern regions of Africa and Zambia in particular. Some coalescent Dambos in Mushota and Mulonga areas of Luapula province are evident and form wide tracts of land available for agricultural use. This observation seems to point to the fact that rainfall is a major contributor to Dambo recharge rather than farmers' land use practices which have been constant and stable over time. It is felt by most Dambo users that in the past much of the rainfall fell over prolonged periods in gentle, even shower intensities so that most of it infiltrated into the ground, whereas in recent years, the bulk of the rain falls in short heavy thunderstorms which mostly runs off to rivers as waste.

Dambos which are usually described as being dry because of their dry surfaces, have their water tables within 2-5 m from the soil surface from which water can be abstracted for irrigation, using buckets or low-lift manually operated suction treadle pumps.

Daka (1992-1997) in hydrological research memoranda alludes to farmers' observation in Luapula province in which rainfall is regarded as the main cause of recharge of Dambos or the lack of it for dryness. Recharge to the Central zone emanates from the seepage zone. Although the Central zone may be having a low water table at the peak of the dry season, it quickly exhibits excess water above the soil surface during the rain season. He further argues that recharge is more pronounced with precipitation than other factors. However, a noteworthy point is the importance of having vegetation in the upper catchment of the Dambo. Since this zone is characterized by sandy soils, infiltration rates are higher here than in the central zone where soils are clayey in nature.

Water in the upper grassland zone moves by both surface flow and sub-surface flow to the transition/seepage zones where it appears above the soil surface and moves as run-off to the central zone. Low infiltration rates in the central Dambo zone often cause inundation of water of which it becomes a permanent feature in high rainfall areas. This phenomenon would probably be the main cause of low pH values in such soils and formation of some peat soils due to incomplete oxidation of organic matter. Because of a thick layer of sand being underlain by clay soil in the seepage and central zones, water is kept in a sponge of sand and released later to contribute to Dambo wetness.

The wetness varies throughout the year according to the evolution of the water table which is a function of some climatic factors such as temperature, rainfall recharge and evapotranspiration, soil physical conditions (texture) and aquifer formation in the catchment area. Dambos in high rainfall areas exhibit more flooding/wetness conditions than in arid and semi-arid areas. A common feature is the fact that water tables will be resident within 1 - 3 m regardless of the extremity of dryness in a drought year as experienced in the year 1992 which was the worst drought ever recorded in the history of tropical Africa (Daka, 1997).

The processes described above result in most central areas of Dambos becoming waterlogged in the rainy season. In dry season groundwater tables may be between 0.1 and 2 meters below ground level. The various zones of the Dambo are associated with different water tables and different levels of recession during the dry season (Daka, 1993; Raussen *et al*, 1996).

In years with low rainfall the groundwater table declines considerably, which at times prevents farmers from irrigating. However, with one season of normal rainfall following, the normal groundwater tables are reached again (Raussen *et al*, 1996; Andreini *et al*, 1995). There appears to be no study suggesting a long-term reduction of groundwater levels in Dambos. McFarlane (1995) found evidence that over longer periods (25000 years) water tables in Dambos of Malawi were considerably lower, e.g. 6 meters. This resulted in a lower piezometric head, which must have prevented discharge of the deep, base rich groundwater into the Dambo.

The role of surface runoff from the watershed seems to vary. Andreini *et al* (1995) and Bullock (1995) argue that it plays a negligible role for the Dambo hydrology. Farmers in Zimbabwe, however, report that without water conservation measures which reduce surface runoff and enhance infiltration at the Dambo margin, the water tables in the Dambo would recess too much for dry season gardening to easily take place (Phiri, 1993).

Evapotranspiration from both the watershed and the Dambo influence the Dambo water balance. McFarlane's (1995) research from Malawi indicates that the widespread deforestation of the watershed to open this land for growing shallow rooted annual crops conserves groundwater through reduced evapotranspiration. Consequently this leads to higher groundwater levels. This raises the piezometric head, prompting increased upward discharge of subsurface water in Dambo zones where the upper clay layer is thin or where constrictions to the subsurface flow, e.g. rock outcrops, occur. This increased point-discharge could be the main factor leading to gully erosion in Dambos.

Daka (1998) agrees with other authors, like Chidumayo (1986), that Dambos are not independent systems but are rather interconnected to the surrounding watershed and the hydrologic cycle. Their sustainable utilization would thus largely depend on proper catchment management and water control.

Past research alluded to above, have clearly indicated that presence or formation of sandy soil layers on adjacent slopes are important for intercepting surface run-off and converting it to base flow which is important for recharging Dambos. To enhance this attribute, the Dambo watersheds and margins should be well vegetated and protected from erosion.

While it is evident that Dambos recharge in the dry season as a result of trees shedding their leaves and reducing evapotranspiration, it does not imply that removal of vegetation in the watershed while not caring for erosion and gully control would promote recharge. On the other hand growing of annual crops which is like vegetation replacement, does not result in water table recession since water loss from these crops is negligible. However, Bullock (1995) and McFarlane (1995) report that the role of possibly reduced infiltration and consequently increased run-off from the deforested catchment areas remain unclear.

Previous studies, e.g. throughout much of the colonial period, hold a different concept, in which surface water flows are of much more importance. While this might be the case in some environments, this perception has to be reviewed in the light of the above recent studies.

During crop cultivation in Dambos, farmers have observed that most of the water drawn from hand dug wells is recycled back to the water table by way of deep percolation. The lost water does not contribute to any meaningful recession of the water table.

1.5.2 Small-scale Informal Irrigation and its influence on the water

Without significant support from agricultural institutions, small-scale farmers have developed irrigated cropping in Dambos for several centuries. They grow cereals and tuber crops during the rain season and vegetables during dry season while perennial crops, fruits in particular, are also grown (Raussen *et al*, 1996). In Zimbabwe paddy rice was grown in the center of the Dambos and is reported to have been the main staple for the population, while vegetable gardens prevailed at the fringes of the Dambo (McFarlane, 1995; Mharapara, 1995).

When European farmers settled in southern Africa they also began using Dambos. Unlike local farmers they used rather massive drainage methods and unsuitable crops, e.g. tobacco, which led to severe gullying and created the perception that Dambos were a fragile environment. This resulted in the introduction of a legislation that made Dambo cultivation illegal.

In spite of the legal restrictions small-scale farmers continued to crop at least at the fringe of Dambos, but rice cultivation reduced drastically and maize grown in the uplands, became the main staple (McFarlane, 1995; Mharapara, 1995). In Zambia and most tropical African countries where Dambos occur, no legislations banning the use of Dambos exist. Traditionally in Zambia, small-scale farmers have utilized Dambos to grow both food and cash crops, some of which include maize, beans, peas, pumpkins, vegetables, rice, potatoes and fruit trees. Cattle grazing has time immemorial been practiced in Dambos where livestock rearing is common. Dambo gardens in Zambia are called **sishango** among the Lozi, **dimba** among the Cewa and **Fisebe** among the Bisa and Lala (Trapnell, 1953; Priestley and Greening, 1956; Trapnell and Clothier, 1957). Kwaw-Mensah (1996) gives a clear outline of the excellent vegetable production by such small-scale farmers in Dambos on the banks of the Zambezi river in the Senanga district in western Zambia. The gardens in which these crops are grown are usually small (0.25 - 1.0 ha) and they have had to cope with constraints such as flooding and drying of Dambos. In order to cope with flooding, traditional technology has involved making of ridges, mounds or banks in between trenches or furrows in order to create drainage in the root zone. These structures vary widely in size depending on the prevailing groundwater levels, soils and crops grown. According to their observation of the Dambo water regimes, farmers make beds at ground level in relatively dry Dambos and raise beds to more than a meter height where waterlogged conditions prevail.

Farmers' choice of suitable crops is usually related to the more general hydrological condition in the respective Dambo zone, whereas the height of beds is used to adapt to small-scale water variations in the Dambo. By doing so farmers respond remarkably well and efficiently to the variations in water levels that exist within a Dambo (Giesen and Steenhuis, 1995). Water quality in Dambos is generally good and salinity is not a problem requiring any drainage efforts (Daka, 1992).

Most of the irrigation systems developed by small-scale farmers are based on a combination of residual moisture, capillary rise and rope-and-bucket irrigation with water lifted from shallow wells (Raussen *et al*, 1996; Murata *et al*, 1995). These methods allow for small to medium size gardens depending on the natural conditions, availability of Dambo land and labour force.

In the southern parts of Zambia and Zimbabwe where relatively low annual rainfall totals are common, farmers may actively irrigate crops in the rainy season, if dry spells occur. This is only required until the roots have reached moist soil layers (Bullock, 1995). In most cases farmers will however, only irrigate dry season crops, mainly vegetables. Some of these vegetables are raised in nurseries at the end of the rainy season and transplanted into the beds in early dry season.

If residual moisture in the topsoil is sufficient, a single irrigation with watering cans may be sufficient for the seedlings to establish. Thereafter their roots will grow downwards to remain in the zone of capillary rise and no further irrigation may be required (Raussen, Kokwe and Daka, 1998).

Similarly, directly sown crops, e.g. beans, may not require irrigation if planted early in the dry season. If groundwater and capillary rise are not within the root zone of crops, especially for those planted later in the season, they require regular watering. In eastern Zambia about 7 mm of water was applied in a 2-day-cycle during the cooler months June-July and double that mount during the hotter part of the dry season from August to October (Raussen *et al*, 1996). During this part of the year irrigation is the most labour intensive activity in the gardens and actually limits the extent of the area under crops unless use of labour saving technologies, such as the treadle pump for water lifting and clay pots for sub-surface drip irrigation, are employed.

According to studies in Zimbabwe by Andreini *et al* (1995) the irrigation water applied in dry seasons amounted to less than 25% of the evapotranspiration from the vegetable plots. The remaining water is provided from subsurface water. Although irrigation is generally critical to the production of dry season crops, it represents a small proportion of the water consumed. Hence, although farmers' delivery methods are usually very labour intensive, they may be considered efficient because only a fraction of the crops' water requirements have to be actually applied by farmers (Andreini *et al*, 1995). Using traditional irrigation technologies, the relative increase in evapotranspiration compared to Dambos in their natural state is not very high.

Faulkner and Lambert (1991) found in Zimbabwe that when 10% of the Dambo area is cultivated, evaporation increases by 60% compared to that of an undisturbed Dambo. This resulted in a depletion of the aquifer by 17%, which the authors consider as having little effect on the moisture regime.

The authors conclude that an extension of Dambo cultivation will not have significant effects on the moisture regime of the Dambo if the cultivated area is less than 10% of the Dambo area or 30% of the total catchment area, whichever is smaller. Farmers who usually do not see the water tables in their gardens affected by their neighbours' irrigation activities (Faulkner and Lambert, 1991) confirm this rather conservative estimation. In Zambia it is observed that often much more than 10% of the Dambo area is irrigated without farmers realizing any effects on the groundwater table.

A further increase of the area under irrigation in Dambos may be possible without threatening its water regime through irrigation methods (such as clay pot and drip irrigation and application of mulch) that reduce evapotranspiration. Murata *et al* (1995) compared these efficient irrigation methods in southern Zimbabwe. The introduction of mechanized pumps (whether manual, draught or engine powered) may pose a serious risk for the Dambo water regime if irrigation water quantities are not limited to safe levels, however.

Considering the heterogeneity of Dambo hydrology, a detailed characterization of the respective Dambo water regimes is required before the introduction of water lifting devices. However, farmers are very interested in such labour saving equipment. The treadle pump development as a technology for irrigation in Dambos is one such equipment which can be used harmoniously in Dambo systems as its discharge is modest (1.5 l/s) and most of the water applied on the Dambo soil either percolates back to the shallow water table or is taken up by the crop.

Irrigation of areas outside the Dambo with water from the Dambo may pose a serious threat of groundwater depletion and should only be considered after hydrological studies have proven the sustainability of such methods for a particular area (Andreini *et al*, 1995). Experiences with such approaches have left parts of the wetland either too dry or too wet (Giesen and Steenhuis, 1995).

There are fears that over-drainage of Dambo soils may cause irreversible drying, leading to acidification and loss of organic matter and associated fertility (Kokwe and Daka, 1996; Giesen and Steenhuis, 1995). In most of the southern parts of the region, drainage systems beyond individual gardens are not an issue. In the northern areas with higher rainfall, some form of Dambo drainage beyond individual gardens might be required. The variability of the water regimes within a Dambo is a major obstacle for uniform drainage to take place. Trafficability is not an issue for small-scale farmers and they usually consider management of high water tables easier than to cope with too low water levels. Giesen and Steenhuis (1995) therefore suggest a restrained engineering approach to Dambo drainage. Such an approach should not attempt to prevent every possible drainage problem but acknowledge the technical capacity which exists at farm level. Any drainage effort should therefore allow flexibility at the farm level.

1.5.3 Sustainability issues

The wide belief that cropping in Dambos is the main cause for their degradation is not supported by most studies. Raussen *et al* (1996) found no serious degradation in Dambos in eastern Zambia where they have been used for decades to intensively cultivate vegetables and other crops in gardens. Sustainable use of Dambos is not dependent on technical factors only. Other important factors for the sustainable use of Dambos are of socio-economic nature, e.g. legislation, tenure, and extension. These are discussed in Section 1.8.

1.5.3.1 Soil erosion in Dambos

Erosion was evident in Dambos (or parts of Dambos) used for grazing livestock. Bullock (1995) reports similar findings from Zimbabwe, where contrary to common expectation the most extensively cultivated Dambos are associated with lower incidence of gullying. He observed more gullying in Dambos used for grazing. Raussen *et al* (1996) confirm these findings by the evidence of acid Dambos remaining undisturbed as they are neither used for grazing nor gardening. Overgrazing with subsequent increased insolation and desiccation as well as trampling by cattle is likely to compound gully initiation. But the main cause for gullying in Dambos appears to be deforestation of the catchment areas (McFarlane, 1995; Bullock, 1995). From agricultural practice there is some evidence that surface run-off from the catchment is often not the main agent of gullying. This is supported by observations where gullies advance even when protected by physical soil and water conservation structures.

Further observations from Zimbabwe (McFarlane, 1995) indicate that gullies in the Dambo occur frequently where the clay layers are shallow or where rock outcrops occur. The rock outcrops as well as thin clay layers encourage the point discharge of subsurface water which then causes gullying (see Figure 8). Often these gullies are self-healing. They move in a caterpillar-like fashion upslope: cutting headwards and heal at the downward end (McFarlane, 1995).

Considering this concept of gully formation in Dambos, their control would be possible by reducing point discharge of subsurface water, through:

- Avoidance of groundwater table rise in the watersheds.
- Replacement of natural forests by annual crops needs to be kept to safe limits in order to avoid reduced evapotranspiration in the watershed.
- Increased evapotranspiration from the Dambo within safe hydrological limits.
- Cultivation in Dambos enhances evapotranspiration and thereby increases subsurface
- Recharge of the Dambo groundwater table by subsurface flows from the catchment. This leads to a lower piezometric head and consequently to reduced water discharge at the fringe of Dambos (McFarlane, 1995).

Daka (1998) believes that conservation efforts for Dambos should therefore concentrate on the management of the whole catchment rather than focussing on Dambos alone. The hydrology and erosion processes of Dambos can only be understood and substantially influenced if the whole Dambo catchment system is considered as a unit. Conservation of the catchment is however a difficult task, since it requires a joint effort by all those farming in the watershed. Lack of social cohesion poses a serious obstacle to success. Furthermore, not all farmers cultivating within the catchment might have access to the Dambo and therefore will be less interested to participate in catchment conservation unless they derive other benefits from the catchment management, e.g. sustainable fuelwood supply. Projects for watershed management require full involvement of the communities concerned and have to share with them responsibilities from problem identification through planning and implementation of conservation effort.

Erosion of the levees along rivers because of their mismanagement may have serious negative impacts on Dambo hydrology. Mr. Jacob Zikhali, a farmer along the Pongola river in the Maputoland area of South Africa explained that chiefs have always been very reluctant to allow people to plant on levees alongside the river. If these are cleared of vegetation, they become vulnerable to erosion by the flood waters. If the levees are washed away, the river will scour one big water way and the floodplain will disappear (Victor, 1993). This notion also points to the fact that drainage of water from a Dambo at its outside boundaries, may cause drying up.

1.5.3.2 Disruption and destruction of Dambo systems by engineering structures

Injudicious construction of structures either at Dambo outlets or upstream in the catchments can lead to serious disruption and even permament destruction of Dambo systems.

Damming a Dambo outlet may cause permanent inundation in all its different zones. In the 1970's one of the biggest vegetable producing areas in central New York state, USA, was put out of production because of waterlogging/inundation caused when an interstate highway was constructed across the outlet of the area, which had characteristics similar to those of Dambos. This should serve as a warning of what could happen to a Dambo area upon such development.

In commercial farming areas in South Africa the outlet of a vlei area is often closed off with an earthern wall to create a storage pond for water supply, e.g. stock watering. These ponds are very vulnerable to destruction by floods during heavy rains, such as brought about by tropical cyclones, for example. The result is severe gully erosion, leading to excessive drainage of the Dambo system afterwards, causing it to dry up.

Building of big storage reservoirs in upper cathments can eliminate flooding and thus cause Dambo areas to dry up, with disastrous consequencies for small farmers who are dependent on cropping in the Dambos. A classical example is the Jozini dam in the Pongola river in South Africa. The dam eliminated flooding of the Dambos downstream in which local communities grow their crops, as well as of the pans in which they do fishing. After realizing the impact of this, artificial flooding by opening the sluices of the dam wide, to let out large volumes of water to simulate floods, was done. The initial attempts created big problems, because the natural flooding systems were not properly understood.

A farmer Mr. Petrus Kanini recalls the disruption brought about by the construction of the Jozini dam to the age old farming system: "Before the dam, you knew what to expect. The flood lasted three days, but afterwards when the dam was constructed, the sluices were opened for seven to ten days and the crop rotted." Another farmer Mr. Jacob Zikhali describes how the system used to work; " We started planting at the end of August after the first rains. Most of the crops take 3-4 months to grow i.e maize, pumpkins and water melons. We also planted madumbes and sweet potatoes which grow in flood water like rice. If the flood takes away the mealies (maize), the sweet potatoes and madumbes are still there."

1.5.3.3 The Effect of Dambo Use on Fertility Sustainance

Apart from alterations of Dambo hydrology and erosion processes, depletion of soil nutrients is a potential threat for the sustainable use of Dambos. Most Dambos are rich in organic matter and being depressions surrounded by high ground, act as nutrient depositional areas. This makes them very fertile lands for crop cultivation. Observations indicate that farmers usually maintain soil fertility of their Dambos through regular application of manure, organic debris and fertilizer (Raussen *et al*, 1996). This practice has proven sustainable and no acidification problems have been reported so far. However, micronutrient deficiencies have been reported (Kokwe, 1991). Seasonal fallows with suitable legumes, e.g. Crotalaria spp. are suggested for replenishing nitrogen and organic matter levels (Kokwe, 1991).

Some farmers burn vegetation in Dambos during cultivation (especially on virgin land). In Dambos used for grazing as well, this practice would promote regeneration of new herbaceous plants and grass which are palatable for livestock to graze. On sour or acid Dambos which are deficient in basic nutrient elements, burning would further lead to loss of nitrogen taken up and stored in plant biomass such that if nutrients are not replaced, the Dambo would lose its fertility and become unproductive in the long-run. A major problem which exacerbate fertility loss in Dambos is erosion due to overgrazing which leads to loss of top soil and its nutrient reserves and lowers its soil moisture retention capacity (Daka, 1998).

1.5.3.4 Pollution due to Pesticide Use in Dambos

So far no documented evidence of Dambo pollution due to pesticide use in Zambia exists after more than thirty years of crop production in Dambos. Most Dambo users traditionally use botanical pesticides such as tephrosia, ground hot chili or wood ash dissolved in water and sprayed on vegetables to control pests such as aphids, red ants and red-spidermite. Increasing use of such methods is currently noticeable. Some farmers use agro-chemicals to some extent, but with good knowledge of handling both the chemical and the equipment used for spraying.

These farmers do not use the same well for both domestic and irrigation purposes. Wells used for drawing domestic water are most often located in Dambo margins whereas those for irrigation are located in the seepage and lower grassland zone.

Studies elsewhere in Europe (Hallberg, 1987) have indicated a widespread opinion that pesticides usually do not leach through soils to surface and groundwater. This hypothesis may explain why even users of agro-chemicals in Dambos have not alluded to any form of pollution in Dambos.

Contamination of wells and streams has occurred (Erne, 1970) but was mainly the result of incorrect handling of application equipment (sprayers) and pesticide residues and spray drift. Some pesticides may find their way to water sources through surface run-off to streams or wells in Dambos. Accidents with pesticide use in Dambo gardens have only been apparent through theft and consumption of sprayed vegetables before the pre-harvest period.

1.5.3.5 Degradation and Sustainability: A Question of Skepticism or Reality?

In as much as Dambos have been reported to have been used stably and in a sustainable way by small-scale farmers, it is important that an environmentally friendly approach is adopted in their utilization. Creation of high ridges for free drainage in the root zone and formation of high flat beds without loss of water downstream or outside the Dambo, is a very sustainable way of utilizing Dambos.

Commercialized crop production which entails use of mechanized farm machinery like tractors to make drainage channels leading to outside Dambos, should not be allowed as this would alter the water movement and its fate in which recycling would no longer be the case.

Over-grazing by cattle in Dambos used for crop production as well is reported to be the major cause of erosion and this should be discouraged at all costs. Use of village headmen and chiefs in bringing about awareness among village communities has proven very useful particularly in Eastern province.

Deforestation in the catchment area is another big problem requiring control as this causes erosion and affects the water regime in Dambos since run-off rather than infiltration is promoted. Afforestation should be encouraged in Dambo fringes and their catchment areas in which planting of fuel woodlots would help re-afforestation.

1.5.4 Legal and Socio-economic Issues Related to Dambo Usage

1.5.4.1 Legislation and policy issues

Particularly in Zimbabwe pronounced calls for amendment and moderation of restrictive legislation on Dambo utilization through the Water Act (from 1927, amended 1976) and the 1952 Natural Resources Act have been voiced (Mharapara, 1995; Maseko and Bussink, 1995; Bullock, 1995; McFarlane, 1995). This legislation and similar laws in some neighbouring countries are based on incorrect perceptions of Dambo hydrology and degradation processes.

It is also argued (Maseko and Bussink, 1995) that the legislation was introduced during early colonial periods because through their use of Dambos small-scale farmers competed very well with the new settlers, especially on the rice and wheat markets. These crops performed even better in Dambos than on upland soils because of high fertility levels. Dambos are not a particularly fragile environment but they are highly influenced by the condition of the catchment.

Some critics feel that use of Dambos would reduce downstream water flow and eventually dry out these streams. Although still a matter of debate, Dambos may have much lower influence on streamflow than previously thought.

Notwithstanding the above concerns, the existing legislation is currently rarely enforced considering the importance of Dambo farming for small-scale farmers' livelihoods. Common knowledge points to the fact that current restrictive legislation should be changed and accept that well practiced cultivation in Dambos is sustainable. However, this needs to be accompanied by criteria defining safe limits of Dambo utilization and could furthermore be linked to certain conditions regarding catchment management, e.g. a minimum tree cover. However, laws alone will be insufficient if not accompanied by good extension based on process and adaptive research. Local knowledge of Dambo use is advanced in areas where Dambos have been used traditionally (Kokwe and Daka,

1996) and this knowledge should be made use of. Where Dambo farming is a relatively new venture greater emphasis has to be placed on extension work and education of communities.

1.5.4.2 Land Tenure

Many African countries have a dual law system, especially as with regard to land tenure. This is a relic of the colonial past. Customary laws usually apply in trust, reserve or communal lands while the state land is governed by statutory law (Kokwe, 1991). In the former the allocation of Dambo land to farmers is through chiefs or village headmen. The right of use is guaranteed with the allocation but can usually not be sold or mortgaged. Absentee land ownership is common and artificially increases Dambo land shortage in some areas (Kokwe and Daka, 1996). Equity concerns regarding access to Dambos need to be addressed (McEwen, 1993). Some land tenure issues have also been delt with in Section 1.3.

1.6 Future Scope of Dambo Utilization

Considering the extent and importance of Dambo farming, the question is not whether Dambos should be used but how Dambos can be used in an ecologically and economically sustainable manner. Frequent droughts, widespread soil fertility decline on the upland fields, population growth and an increasing demand for vegetables by the urban markets leave farmers with little choice but to use Dambos which are a fairly robust environment and more productive than upland fields. While labour invested per unit Dambo area is often double that invested on upland fields the average production from them is often threefold to fourfold (Scoones, 1993).

Although Dambos are far less fragile than often thought, there is a need to define conditions for sustainable, extended Dambo use and to set the agenda for comprehensive research and extension work. Many studies have been reductionistic, addressing only one or a few components of a larger system. By doing so the results of the research do not address the complex and dynamic interactions between farmers' activities and the catchment Dambo stream flow system.

As reviewed in this chapter, the hydrology of Dambos is still a matter of many debates and hydrology of Dambos may differ between Dambo types and areas. Kokwe (1993) in a review of technical research on Dambos concludes on the whole that hydrological research in Dambos remains an area of contradictions of findings and perhaps forms one of the greatest challenges to researchers in understanding the Dambo and the resources it avails to life supporting systems.

1.7 Extent, Distribution and Economic Importance of Dambos

In Zambia, there are about 3.6 million hectares of Dambos (Perera, 1980) representing 8.3% of the total arable land. Proper and successful land use of Dambos requires an understanding of water movement, recharge and storage mechanisms and its fate. This information is lacking and to a great extent very little has been documented primarily due to lack of interest by researchers and policy makers in the field of wetland development for decades until only in recent years.

The last thirty years have seen small-scale farmers exploit Dambos for food production whilst at policy level Dambos have been classified as marginal lands for crop production and only suitable for grazing cattle. This is particularly because Dambos remain partially or permanently flooded for most part of the year and would almost always be endowed with fresh grass and some herbaceous plants palatable for cattle. Notwithstanding the above merits, farmers have had to cope with inherent problems such as excessive flooding, soil acidity, heavy soil texture difficult to cultivate and lifting water using buckets to irrigate relatively dry portions where crop production is feasible to mention but a few problems. In the past ten years, Zambia has experienced frequent droughts with the 1992 drought being the worst ever in human history on the continent of Africa. This drought was disastrous as farmers lost livestock and upland crop production was unsuccessful, with widespread food insecurity resulting.

During this period and subsequent years, there has been an increasing demand for use of Dambos to grow crops and graze cattle in them, owing to the moisture potential which prevails for most part of the year and can be exploited for dry season cropping and grazing.

This study has shown that soil moisture potential in upland and lowland Dambos is adequate enough to produce crops even in dry years as seen in the severe drought of the 1991/1992 agricultural season since water tables remain resident within 1-5 m below soil surface. Digging of shallow wells to 8 m levels allowed farmers access to water to grow vegetables for household consumption and sale of surplus for income generation at household level for an extended period in the dry season.

Need for water lifting technologies was however underlined when water was to be drawn from 3-5 m below the ground level using the traditional laborious method of a rope and bucket as this would cut down on the labour investment into Dambo cultivation. This phenomenon shows how Dambos could play a major role in achieving sustainable household food production in the light of frequent droughts which are characteristic of tropical and sub-tropical Africa. Most importantly is the need to derive sustainable ways of utilizing Dambos which are considered as environmentally vulnerable ecosystems yet very resourceful ecologies for sustaining human livelihoods. With regard to this, the study has addressed the following fundamental objectives.

1.8 Objectives of the Study

The initiated study seeks to fulfill the following specific objectives:

1. To develop a technological package that would entail increased food production through sustainable use of Dambos based on sound knowledge of farmers and scientific backing.
2. To identify crop production constraints in Dambos using a participatory rural appraisal approach.

3. To identify farmers' solutions to some constraints and the rationale used in arriving at them with a view to backing this knowledge with empirical scientific evidence from the study observations.
4. To investigate some mechanisms that recharge Dambos to become wetlands in dry lands through monitoring, quantifying and characterizing rainfall and water-table variations.
5. To establish the effects of water-table variations on the moisture storage and soil profile chemical development of Dambos with relevance to crop production.
6. To characterize farming or cropping patterns in Dambos and establish a cropping calendar according to agro-ecological zones in which the Dambos occur.

CHAPTER 2

MATERIALS AND STUDY METHODOLOGIES

2.1 Site Selection

Three contrasting sites in Agro-ecological Zones I, II and III were selected for the study. Annual rainfall totals of 400 mm - 800 mm; 800 mm - 1000 mm and 1000 mm - 1500 mm in Agro-ecological Zones I, II and III respectively, are major parameters of relevance to understanding Dambo development and utilization for crop production.

2.2 Land Use and Constraints Analysis

In the context of development efforts, situation analysis involved investigation of features and characteristics of the Dambo areas with the potential target groups of farmers in three different agro-ecological zones of Zambia i.e. Region I (Noole Dambo); Region II (Mugabi Dambo) and Region III (Chipala Dambo in Ndola rural District). Intervention areas regarding crop production in Dambos were identified using Participatory Situation Analysis (PSA) involving all relevant groups in an active way with due regard to gender consideration. Other Dambo areas of Kanchele, Siachitema, Chalata and Musofu were surveyed to assess the socio-economic impact of the developed technology.

Land use practices in each of the selected Dambos were characterized. Crop production constraints were highlighted and prioritized by farmers. Cropping calendars were developed for each of the selected sites. Participatory approaches helped to identify real-life situations and to understand the socio-economic implications of Dambo use and solutions to constraints related to their uses. This does not necessarily mean involving everybody in everything but rather aims at integrating all concerned groups for specific function and potential. Catchment sites were described *in situ*, their geology studied from a standpoint of hydrology which is being monitored in detail.

2.3 Catchment Hydrology of Dambos

Noole, Chipala and Mugabi Dambos were characterized in terms of their hydrology and the effects that climatic parameters such as temperature, evapotranspiration and rainfall would have on their wetness attributes. Soil physical parameters and their relevance to water movement were studied. Infiltration tests, using the double ring infiltrometer method, were carried out. Dambo major zones were delineated and characterized in terms of slopes, wetness and limitations for crop production.

2.4 Water Table Monitoring

Piezometric wells were sunk at Noole, Chipala and Mugabi Dambos. Auger holes of 75 mm diameter were made using a galvanized pipe and hand auger to drill up to 4 m deep to the water table in a sand layer of each of the Dambo zones, forming a cross-section. Aluminium pipes of 3 m lengths were cut and made ready to be inserted in the auger holes. The 2 m bottom end of each pipe was perforated by cutting small slots using a hack saw blade. The pipes were pushed in each of the auger holes with the slotted part in the bottom side of the auger hole and only a 30 cm length of the pipe was left above ground surface.

The slots allow water to enter the pipe and remain in equilibrium with the water table. Water table measurements were done using a whistling tape which is graduated throughout its length. The tape is lowered into the piezometric pipe and upon touching the water surface, it whistles, signalling the presence of a water table. Readings were recorded from the whistling measuring tape every two days throughout the year. Records from the author's research funded by the International Foundation of Science were used in order to show trends in wetness and response to climatic changes.

2.5 Soil studies

2.5.1 Soil Moisture Availability

Water holding capacities (WHC) of all soils studied were determined on undisturbed soil samples placed in a soil-moisture extractor at pF 2.0 (equal to 1.45 p.s.i or 0.1 bar or 10 kPa tension) and pF 4.2 (equal to 225 p.s.i. or 15 bar or 1500 kPa tension). The field capacity (FC) ranges between pF 1.8 and 2.5, at which pF 2.0 was applied as the average value. The samples were also subjected to soil-moisture extractions at 0.3 bar (30kPa), 1 bar (100kPa) and 2 bar (200kPa) pressures as well, in order to cover an irrigation soil moisture depletion range between field capacity and permanent wilting point (PWP). The soil moisture content between field capacity and permanent wilting point is considered as the soil-water available to plants. Five soil profiles were sampled with five soil samples from each profile sampled at 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm soil depths. The available moisture capacity is expressed in a meter profile depth.

2.5.2 Particle Size Analysis

Particle size analyses were done using the International pipette method as described by Loyland and Stuhaug (1987) in which 20 g of soil from each sample was treated with sodium pyrophosphate as a dispersing agent, stirred for 5 minutes in a high speed stirrer and made up to a volume of one liter in a hydrometer jar. Pipette samples were taken at the appropriate times to measure suspended silt and clay. Particle sizes were measured in percent for sand, clay and silt.

2.5.3 Bulk Density

Bulk density is defined as the ratio of the mass of a unit volume of dry soil, air space included. It is expressed as $g.cm^3$ or $kg.m^3$. Bulk density is required for the determination of soil moisture contents on volume percentage basis. In general bulk density is also an indicator of the soil structure. Five soil cores of 100 cm^3 each per sampling site were dried at 105^oC then weighed and the bulk density calculated.

2.5.4 Soil Profile Description

Soil profile pits to a depth of about 100 cm were dug. For practical purposes of the field applications and understanding of various Dambos in different locations and their behaviour to soil chemical changes as a result of water movement in the profile, soil sections of 20 cm depth were preferred. Descriptions were made in the 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm soil layers. Munsell colour charts were used for soil colour annotation.

2.6 Development of technological packages

2.6.1 The Treadle Pump

On the basis of constraints analysis for crop production based on current land use practices, prioritization and ranking of constraints in terms of their importance was done. Water lifting being the most limiting factor for crop production, development of a treadle pump as a device to lift water was embarked on. A prototype from Bangladesh was obtained, tested with farmers in the field and modified to suit Zambian conditions,eg. for use where rivers form banks and flat terrains like Dambos. The device was modified with the aid of small metal fabricating manufacturers and later tested in the field. The tests were conducted for suction lift of the device, discharge rate, energy requirements for manual pumping, durability and adaptability.

After an appraisal by farmers in the field, mass production with the help of an NGO, i.e IDE (International Development Enterprises), was embarked on by training small producers in the manufacturing of the pump. This would ensure local availability. Quality control of the manufactured pumps was conducted by trained staff from IDE.

2.6.2 The Clay Pot Sub-surface Irrigation

The clay pot was identified to have attributes of discharging water through its micro-pores which could in fact effect sub-surface drip irrigation when buried in the ground with only the neck and mouth appearing above the ground surface level. Water is poured into the clay pots using a watering can or a hose pipe. The mouth is covered with a clay lid in order to eliminate direct evaporation of water from the clay pot.

The lid also prevents rodents and birds from drinking the water from the pots and thus ensuring that all the lost water is available for uptake by the plants that are planted adjacent to the clay pot. The clay pots vary in sizes and capacities. Clay pot sizes of 1 liter to 5 liters were used in the evaluation.

2.6.3 Technology Dissemination

To disseminate these technologies to a wide range of farmers, field demonstrations were conducted between 1997 and 1999. Demonstrations were conducted using the massive network of technical staff of the Ministry of Agriculture Food and Fisheries (MAFF) in the selected Dambo areas and later throughout the country due to popular requests from farmers. To make the technologies sustainable, an affordable price was negotiated from manufacturers of the treadle pump and the rural women who make clay pots. A retail network of treadle pumps in five provinces of Zambia was created by recruiting shop owners already dealing in sales of agricultural implements. The retailers were taught how to install, operate, maintain and repair the pump so that they too would show the farmer how to undertake correct installation and operation in the field. Marketing officers from IDE and MAFF technical staff helped to carry out this function in the demonstration areas which propelled massive adoption of the technology.

2.6.3.1 Technology Adoption and Evaluation

The technology development and adoption was coupled with a socio-cultural and economic impact evaluation on its use, farming system, the community and the dissemination chain, created i.e. the manufacturers of the pump, wholesale distributors, retailers and farmers as consumers in order to measure its impact and contribution to household food security and the country's economic growth at grassroot level.

CHAPTER 3
ENVIRONMENTAL CONSIDERATIONS OF DAMBO DEVELOPMENT

3.1 Dambo Classification

3.1.1 Introduction

Several definitions and classifications of Dambos have been developed by many research workers (Daka and Gondwe, 1998). M^{c}Cartney ***et al***. (1998) alludes to the fact that Dambos are complex systems that do not fall easily into one discrete class. Many classification systems and definitions have been developed so far but not one has been universally accepted to date.

Many authors have defined Dambos on the basis of their biased perception but with certain attributes which fit common knowledge of what Dambos may be. This chapter presents chemical and physical properties as actually obtained by means of analyses. These characteristics, which are based on quantitative data, are applied according to the suggested key modifiers which eliminate subjective and professional biased interpretation of Dambos.

The following key modifiers as suggested by M^{c}Cartney and Daka (1998) are applied to expand on Mackel's simplified definition of a Dambo which states that:

"Dambos are seasonally waterlogged, predominantly grass covered, depressions bordering headwater drainage lines".

The modifiers presented in Table 8 may be used to expand on the above definition to define individual Dambos with empirical scientific evidence. Thus Dambos would have a definition embracing vegetation type, chemical nature, wetness indication and present land use. Chemical data are used to decide on the acidity levels.

Two Dambos with greatly different characteristics, i.e. Fikolwa and Mudodo from the Central and Southern districs of Zambia respectively, were selected to illustrate the use of these criteria for the classification of Dambos.

3.1.2 Soil Chemical Properties and Fertility Status

3.1.2.1 Sampling and Analytical Procedures

Soil profile pits measuring 1m x 1m x 1 m were dug in each of the Dambo central/seepage zones where most vegetable growing activities take place. The month of August was chosen for sampling as this represents the peak dry month when it is expected that the antecedent soil moisture levels for most upland and Dambo areas will have dropped considerably and so would be the acidity levels. Soil profile descriptions were done and by cutting from the side walls of the pits with a knife, soil samples were taken from the following soil profile pit layers; 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm.

Samples for chemical analysis were packed in clean plastic bags and those in undisturbed sampling metal cores were put in a specially made sample carrier. All the samples were then taken to the laboratory at Mount Makulu Central Research Station in Zambia for both hydro-physical and chemical analyses.

Prior to laboratory chemical analysis, the soil samples were air dried at room temperature, ground by a mortar and pestle and passed through a 2 mm sieve. Both the top and sub-soil were analysed for pH, organic carbon, phosphorus, potassium, calcium, magnesium, sodium and electrical conductivity (EC).

Exchangeable bases (Ca^{++}, Mg^{++},K^{+} and Na^{+}) were extracted by leaching the samples with a 1N solution of ammonium acetate buffered at pH 7.0. Ca^{++} and Mg^{++} were measured by atomic absorption spectrphotometry and K^{+} and Na^{+} by flame photometry.

Organic carbon was measured by the Walkley-Black method. Available phosphorus was determined by the Bray's No.1 method (Knudsen, 1980).

Soil pH was determined in 0.01M $CaCl_2$ using a soil to salt solution ratio of 1:2 on volume basis. EC was determined in a saturation extract (Qien and Krogstad, 1983).

Effective Cation Exchange Capacities (ECEC's) were determined by summing up of extracted K^{+}, Na^{+}, Ca^{++} and Mg^{++} found in extraction with ammonium acetate and exchangeable acidity from a soil extracted with 1N KCl. Exchangeable acidity was determined by titrating the extract with 0.05 N NaOH back to neutral (McLean, 1965).

The determination of the bulk density is described in section 2.5.3 of Chapter 2 as described in Qien and Krogtad (1983).

3.1.2.2 Results and Discussion

Tables 1 and 2 present soil analysis data for Fikolwa and Mudobo Dambos. Soil chemical information presented in Tables 1 and 2 is revealing in terms of environmental conditions in the two Dambos. Fikolwa Dambo presents itself with higher organic matter content (2.82%) than Mudobo (1.46%). However, both Dambos confirm the decreasing organic matter with increasing soil depth up to 100 cm. Loyland and Stuhaug(1987) observed that soil physical properties of most Dambos are strongly related to organic matter content which in the top soil varies from 1.5% to 33%. In the sub-soil, they found that organic matter content varies from 0.5% to 26%. This observation agrees with results of this study in which decreasing

organic matter from the top soil layer to the subsurface layers is observed as a trend.

A perculiar high subsurface organic matter content is observed in the 20-40 cm layer at Fikolwa Dambo due to heavy root penetration of the vegetation in the light sandy clay loam soil. The over-turning and burying of organic matter during land preparation created conditions for intensive root penetration which are important for this increase of organic matter in this layer.

Inundation of some Dambo zones promotes accumulation of organic matter which remains partially undecomposed for some time until the water has receded or the soil has been drained, when oxidation due to proper aeration takes place. At these times most of the accumulated organic matter decomposes and releases nutrients to the soil to make the soil fertile.

It would appear that in most Dambos organic matter accumulation is important in the upper 20 cm layer of the soil profiles of the central/seepage zones in the two Dambos. Farmers believe that its cyclic utilization and accumulation is a major attribute of soil fertility sustainance.

Table 3 gives some threshold value ratings of organic matter, carbon, nitrogen and phosphorus. Organic matter is an important soil constituent, being the base for biological activity and influencing the agricultural characteristics of the soil: base saturation, CEC or ECEC, phosphorus content, nitrogen cycle and structure. The soil colour has often been used as a hint to the organic matter status of the soil; a dark colour particularly in Dambo topsoils being an indicator of high organic matter content. The quality of organic matter is influenced by both the organic carbon and nitrogen percentages. Nitrogen essentially stimulates microbiological activity. If the soil is acidic and temperatures are too low for mineralization to occur, microbiological activity is restricted and organic matter accumulates without much decomposition taking place. Both top soils (0-20 cm) at Fikolwa and Mudobo show high ECEC levels of 14.00 cmol/kg soil and 29.05 cmol/kg soil respectively, decreasing with low pH values in deeper soil layers. However, Mudobo, despite a lower organic matter content, shows higher ECEC values than Fikolwa.

Table 1: Chemical data of the soil profile from Fikolwa Dambo central zone.

Soil depth (cm)	pH ($CaCl_2$)	Org.C (%)	P-Bray-1 (mg/kg)	K ($cmol_+$/kg)	Ca ($cmol_+$/kg)	Mg ($cmol_+$/kg)	Na ($cmol_+$/kg)	CEC (cmolc/kg)	EC mS/m
0-20	4.7	2.82	23.00	0.80	2.50	2.20	0.98	14.08	2.06
20-40	3.9	0.54	5.00	0.15	0.60	0.60	0.19	5.10	0.54
40-60	4.0	0.29	12.00	0.09	0.40	0.30	0.11	1.85	0.16
60-80	3.7	0.18	2.00	0.10	0.40	0.30	0.14	1.50	0.25
80-100	3.8	0.25	2.00	0.10	0.50	0.40	0.16	2.10	1.72

Table 2: Chemical data of the soil profile from Mudobo Dambo central zone.

Soil depth (cm)	pH $CaCl_2$	Org.C %	P-Bray-1 (mg/kg)	K ($cmol_+$/kg)	Ca ($cmol_+$/kg)	Mg ($cmol_+$/kg)	Na ($cmol_+$/kg)	CEC (cmolc/kg)	EC mS/m
0-20	5.7	1.46	36.00	0.65	4.70	2.30	0.81	29.05	4.00
20-40	4.4	0.41	6.00	0.40	0.90	0.60	0.51	4.71	1.00
40-60	4.0	0.23	4.00	0.15	0.60	0.40	0.20	1.95	0.38
60-80	4.1	0.16	3.00	0.10	0.50	0.30	0.14	2.40	0.27
80-100	4.1	0.11	5.00	0.08	0.50	0.20	0.12	1.76	0.25

Table 3: Ratings of organic matter, carbon, nitrogen and phosphorus levels in soils.

Ratings	Total O.M (%)	Total Carbon (%)	Total Nitrogen (%)	C/N	Available- P Bray-1 (mg/kg)
Very high	>6.0	>3.50	>0.30	>25	-
High	4.3 - 6.0	2.51 - 3.50	0.226 - 0.300	16-25	>40
Medium	2.1 - 4.2	1.26 - 2.50	0.126 - 0.226	11-15	10 - 40
Low	1.0 - 2.0	0.60 - 1.25	0.095 - 0.125	8-10	<10
Very low	<1.0	<0.60	<0.095	<8	-

Sources: Ilaco(1981) and Young (1976)

Because of higher wetness throughout the Dambo at Fikolwa than Mudobo, the topsoil at Fikolwa has a lower **electrical conductivity** of 2.06 mS/m than the 4.00 mS/m for the top soil at Mudobo (Tables 1 and 2). At the 20-40 and 40-60 cm depths the values at Fikolwa indicate (as could be expected) more leaching than at Mudobo. At 60-80 cm depth the values for the two Dambos were equal. At 80-100 cm depth the value for Fikolwa was mucher higher than that at Mudobo, indicating some accumulation of salts leached from the upper layers to this layer at Fikolwa. It must be remembered, however, that all these values are very low and that the differences are of no practical significance.

The topsoil **pH** levels of 4.7 and 5.7 at Fikolwa and Mudobo respectively, are also a manifestation of a higher degree of leaching of bases from the wetter Fikolwa Dambo (Tables 1 and 2). The presence of higher organic matter in the central zone of Fikolwa probably also contributes to the lowering of the pH, due to the release of acids during decomposition. The difference in topsoil pH levels between the Dambos is big and important. A pH of 5.7 is favourable, but 4.7 is too acid and plant nutritional problems may develop. There is however no significant difference in subsoil pH between the two Dambos. The trend at both sites is that of a sharp decrease in pH below the top 20 cm layer to very low values. Below 20 cm the pH values remain constant to 100 cm depth. The usual burning of vegetation during land clearing could be a contributing factor to higher topsoil pH levels because ash with higher base content may have a liming effect. There may also be a higher buffering effect to pH change due to the higher organic matter level.

According to Moorman and Van Breemen (1978a) soils with high organic matter contents are commonly deficient in phosphorus, potassium, copper and molybdenum.

According to Brady (1974), both phosphorus and potassium contents of peat are low with potassium being exceedingly so in compariosn with mineral soils. Maximum phosphorus availability normally occurs at pH 5.5-7.0 and decreases below pH 5.5 and above pH 7.0. According to the ratings in Table 3 available phosphorus levels in the topsoil (0-20 cm) layer were medium (23 mg/kg) and high (36 mg/kg) for Fikolwa and Mudobo Dambos respectively (Tables 1 and 2). Although the authors quoted regard 23 mg/kg as medium, it is actually adequate for optimum production of crops. Subsoil P levels are low in both Dambos, which is normal for subsoils, except for the 40-60 cm layer at Fikolwa with a P content is quite higher than normally found in subsoils.

Generally, phosphorus levels are usually low in Dambo soils under natural conditions. When phosphorus is deficient, addition of organic matter or manure will increase the availability of soil phosphorus. At Fikolwa the moderately high level of phosphorus in the top soil can be attributed to accumulation of moderate applications of kraal manure. At Mudobo addition of kraal manure to Dambo garden soils is probably the source of the relatively high topsoil phosphorus level. The latter is promoted by the presence of a cheap source of manure from the high population of cattle in the area. Kraal manure is a very good alternative source to inorganic fertilizers whose prices are unaffordable for smallholder farmers. Soil sub-mergence increases the availability of phosphorus (Mitsui, 1960 in: Tadano and Yoshida 1978) and where wetland crops like rice are grown in lowland valley Dambos, e.g in the Western province floodplains and in Eastern and Luapula provinces, phosphate application becomes less important.

Calcium, magnesium, and potassium tend to be very high in strongly alkaline soils and will show low levels when acidic conditions prevail. Ratings of exchangeable bases that can be applied to indicate the base status of the two Dambo soils are given in Table 4.

Table 4: Ratings of exchangeable bases (in cmol$_+$/kg)

Ratings	Ca^{++}	Mg^{++}	K$^+$	Na$^+$
Very high	>20	>8	>1.2	>2.0
High	10-20	3-8	0.6-1.2	0.7-2.0
Medium	5-10	1.5-3.0	0.3-0.6	0.3-0.7
Low	2-5	0.5-1.5	0.1-0.3	0.1-0.3
Very low	<2	<0.5	<0.1	<0.1

Source: Ilaco (1981).

The soils at Fikolwa would generally be expected to exhibit lower levels of bases and base saturation than Mudobo Dambo, because of the higher degree of leaching at Fikolwa. This is indeed the case in the top and middle layers (Tables 1 and 2). In the deepest layer (80-100 cm) the situation is reversed, as was also the case with EC, again indicating accumulation of soluble salts and bases in this layer at Fikolwa due to some restriction to leaching beyond this layer.

Similar to the situation with phosphorus, there is a sharp drop in exchangeable base content between the topsoil and the subsoils at both Dambos. This is true not only for the total base content, but for each of the individual bases also. The only exception is the small drop in potassium content between the 0-20 and 20-40 cm layers at Mudobo Dambo.

The results in Tables 1 and 2 show high **potassium** levels in the topsoil for both Fikolwa and Mudobo Dambos, but also medium levels show in the sub-soil (20-40 cm) for the latter. One source of high topsoil K^+ is burning of grass and accumulated organic matter, particularly at Fikolwa. Burning of vegetation in Dambos is not uncommon, particularly when land preparation takes place, and it is a source of potassium. Burning also increases the available bases from the resulting ashes and thus high levels of EC would manifest. At both Dambos the subsoil potassium levels are low to very low (except in the 20-40 cm layer at Mudobo).

Sodium levels are high in the topsoil and low in the subsoil at both Dambos, except in the 20-40 cm layer at Mudobo where it is medium. It is a common feature that groundwater that seeps laterally through the soils of adjacent uplands to a Dambo may be a source of sodium, and various plant nutrients that accumulate in the soil of the Dambo. The high sodium levels, and especially the high ratio of sodium to cations like calcium and magnesium, are matters for concern since it may cause dispersion of the soil and poor physical conditions.

3.1.3 Soil Physical Properties

3.1.3.1 Sampling and Analytical Procedures

Undisturbed 100 cm^3 sample cores were taken for the determination of soil moisture retension capacities at different tensions, using pressure-membrane extraction apparatus operated at 0 kPa, -10 kPa, -33 kPa, -100 kPa, -200 kPa and -1500 kPa (Richards, 1948).

Soil textural classes were determined by using the International pipette method as described in Section 2.5.1. Bulk density was determined by the method described in Section 2.5.2.

3.1.3.2 Results and Discussion

The two Dambos notably have sandy soils, exhibiting a Sandy Loam (SL) textural class throughout the profiles (Table 5). This physical characteristic is of interest particularly because of the good drainage occurring in the upper grassland and seepage zones. With such good drainage, infiltration of rain water is enhanced in the upper fringes of the Dambo and is responsible for sub-surface flow and recharge to the main Dambo area.

Table 6 shows hydro-physical soil data as determined for soil samples from the Dambos at Fikolwa and Mudobo. **Water holding capacities** of 170 mm/m and 226 mm/m at Fikolwa and Mudobo respectively were found. These are calculated values obtained as a difference between Field Capacity (FC) and Wilting point (WP) measured at –10kPa and –1500kPa respectively (Hansen ***et al.***, 1980).

Hansen *et al.* (1980) described FC to be associated with a soil water tension of about –10kPa for sandy soils and –33kPa for clayey soils. The two Dambos manifest themselves as sandy soils. Soil water holding capacities of soils vary with soil texture, organic material and many other factors.

The Plant Extractable Soil Water (PESW), is the soil water between FC and WP. PESW is the same as the term Available Soil Water (ASW) and is often used for irrigation system design and operation (Ritchie, 1985).

Table 5: **Particle size distribution and textural classification of Fikolwa and Mudobo Dambo soils**.

Fikolwa									
Soil depth (cm)	**Clay (%)**	**Silt (%)**	**Total Sand (%)**	**Very fine sand (%)**	**Fine sand (%)**	**Medium sand (%)**	**Coarse sand (%)**	**Very coarse sand (%)**	**Textural class**
0-20	**17**	**7**	**76**	**5**	**17**	**30**	**19**	**5**	**L**
20-40	**18**	**21**	**61**	**8**	**20**	**21**	**10**	**3**	**SL**
40-60	**11**	**22**	**68**	**7**	**21**	**22**	**12**	**5**	**LS**
60-80	**11**	**20**	**69**	**5**	**16**	**27**	**16**	**5**	**SL**
80-100	**4**	**10**	**86**	**3**	**13**	**32**	**26**	**12**	**SL**
Mudobo									
0-20	**18**	**47**	**36**	**14**	**15**	**4**	**2**	**1**	**SL**
20-40	**16**	**19**	**64**	**13**	**30**	**12**	**5**	**4**	**SL**
40-60	**4**	**18**	**78**	**13**	**34**	**18**	**7**	**6**	**SL**
0-80	**15**	**15**	**70**	**13**	**28**	**13**	**7**	**8**	**SL**
80-100	**8**	**18**	**73**	**10**	**21**	**15**	**11**	**16**	**LS**

In both Dambos the soils have very high soil moisture holding capabilities. Mudobo has a higher Available Soil Water Capacity than Fikolwa Dambo. This is due to the higher percentage of silt and clay particles. Even the fine sand fractions are higher in Mudobo than in Fikolwa, which manifest a higher percentage of coarse sand. Fikolwa, whilst exhibiting higher soil moisture contents at field capacity, has a so much higher soil moisture retention at wilting point that the difference between FC and WP is smaller at Fikolwa than at Mudobo.

Fikolwa Dambo is a wet Dambo whereas Mudobo is a dry Dambo. This is supported by the soil field moisture contents at the time of sampling at the peak dry season in August just before the onset of the rains. Field soil moisture contents at Fikolwa matched those at wilting point in the 0-20 cm and 20-40 cm layers and were higher than its wilting point in the 40-60 cm, 60-80 cm and 80-100 cm layers whereas those of Mudobo were lower than its wilting point, except in the bottom layer (80-100 cm) and some sign of available water in the 40-60 cm layer (Table 6). At Fikolwa there is evidence of a perched water table at 40-60 cm where the soil moisture content of 0.64 cm^3/cm^3 was higher than at 0 kPa soil water tension. This was just above a compacted soil horizon where there was a sharp increase in bulk density from 1 500 kg/m^3 to 1 940 kg/m^3. The fact that at Mudobo field soil moisture contents fell well below the soil moisture content at wilting point indicates the need and importance of irrigation in this Dambo for crops have to survive, particularly because a noticeable root restricting bulk density starts at 40 cm depth, giving an effective rooting depth of only 40 cm.

Table 6: Hydro-physical soil properties of Fikolwa and Mudobo Dambos.

Depth (cm)	Bulk density (kg/m^3)	Field Soil Moisture Content cm^3/cm^3	0 kPa SMC (cm^3/cm^3)	-10 kPa SMC (cm^3/cm^3)	-33 kPa SMC (cm^3/cm^3)	-100 kPa SMC (cm^3/cm^3)	-200 kPa SMC (cm^3/cm^3)	-1 500 kPa SMC (cm^3/cm^3)	Soil Textural class
Fikolwa Dambo									
0-20	1 260	0.24	0.56	0.38	0.35	0.32	0.30	0.24	**L**
20-40	1 580	0.14	0.54	0.38	0.32	0.27	0.23	0.17	**SL**
40-60	1 520	**0.64***	**0.61***	0.39	0.21	0.13	0.08	0.18	**LS**
60-80	1 940	0.23	0.47	0.33	0.30	0.24	0.22	0.20	**SL**
80-100	1 840	0.30	0.44	0.36	0.33	0.26	0.24	0.20	**SL**
Mudobo Dambo									
0-20	1 240	0.15	0.59	0.36	0.30	0.26	0.24	0.20	**SL**
20-40	1 620	0.09	0.44	0.30	0.25	0.21	0.18	0.10	**SL**
40-60	1 790	0.13	0.64	0.41	0.29	0.19	0.15	0.08	**SL**
60-80	1 840	0.09	0.55	0.34	0.23	0.14	0.12	0.07	**SL**
80-100	1 940	0.21	0.48	0.27	0.22	0.17	0.15	0.10	**LS**

SMC = Soil Moisture Content

Fikolwa: Available Soil Water Holding Capacity = 170 mm/m

Mudobo : Available Soil Water Holding Capacity = 226 mm/m

*** High values due to a perched water table.**

Bulk densities in both lower profiles are extremely high (Table 6). Bulk densities from about 1 800 kg/m^3 are considered to totally prevent root growth (Ritchie, 1985). Such values are reached at 60cm in Fikolwa Dambo and 40 cm in Mudobo Dambo. This means that Fikolwa Dambo has only 60 cm effective rooting depth and Mudobo only 40 cm, especially the latter being very shallow for irrigated cropping. The perched water table in the 40-60 cm layer at Fikolwa means that at this Dambo roots will also be restricted to a depth of only 40 cm.

For both Dambos, a high organic matter content in the upper layer (0-20 cm) gives lower bulk densities and higher soil moisture contents under field conditions and at wilting points. It is noteworthy that, because of its influence on bulk density and the water content at wilting point, organic matter actually lower the plant available water content of the soil. This is clear from the data for the difference between field capacity and wilting point for the 0-20 cm layers.

3.1.3.2.1 Dambo Environmental Conditions Governing Water Movement

During the rain season Dambo soils tend to flood, particularly in the central zone. During an excessively flooding regime, most soils would get saturated with water. Water movement in the soil under saturation is much faster than unsaturated soil water movement because the unsaturated conductivity is much slower. Water movement from a water table to the root zone of plants is unsaturated flow. This phenomenon occurs inspite of the fact that a zone of near saturation, called the "capillary fringe", always exists above the water table. Upward movement of water is restricted by unsaturated hydraulic conductivity, which is usually much less than saturated hydraulic conductivity. Some models assume that the hydraulic conductivity is zero below the Field Capacity (Ritchie, 1985). This leads to the conclusion that water for evapotranspiration comes from rainfall, irrigation or root movement into a moist soil zone. Unsaturated flow of soil water will take place inside and to the root zone when portions of the soil become dry. Water also can be supplied to the roots from shallow water tables.

3.1.4 Ground Water (Well Water) Quality for Irrigation

3.1.4.1 Sampling and Analytical Procedures

Water samples were collected from six hand dug wells used as sources of irrigation water in different Dambos. Clean water sample bottles were used to collect the water by filling them up and covering them with a lid supplied with a seal to ensure the bottles are not unduly opened. The bottles were then taken to the laboratory at Mt. Makulu Central Research Station for analysis of pH, P, K, Ca, Mg, Na and electrical conductivity. Sodium Adsorption Ratio was calculated by using the Gapon Equation (Kelly, 1948) as follows:

$$\mathbf{SAR = Na^{+}/((Ca^{++} + Mg^{++})/2)^{1/2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

3.1.4.2 Results and Discussion

Chemical data for water samples from six wells used as sources for irrigation water in Dambos are presented in Table 7.

Table 7: **Water analyses for seven wells in Siachitema, Fikolwa, Mudobo and Kanchele Dambos.**

Well Location	pH (Cacl$_2$)	P (mg/kg)	K (cmol$_+$/kg)	Ca (cmol$_+$/kg)	Mg (cmol$_+$/kg)	Na (cmol$_+$/kg)	EC (mS/m)	SAR
Mudobo	6.4	7	18.90	0.80	2.10	14.50	2.10	12.04
Siachitema	6.1	2	5.00	1.20	0.70	5.50	0.57	5.80
Kanchele-well 1	6.1	2	11.40	1.00	0.90	10.30	0.83	10.60
Kanchele-well 2	6.2	3	8.10	0.80	0.80	7.50	0.85	8.38
Kanchele-well 3	8.7	2	5.90	7.20	0.30	8.40	1.65	4.34
Fikolwa	6.3	2	5.00	trace	trace	6.50	530	>15

From the results in Table 7 it is evident that the well water from Mudobo Dambo, which has granitic rocks as parent material, shows a lower **EC** level (2.10 mS/m) than Fikolwa (530 mS/m) with mica schist as parent material. Water with an electrical conductivity of more than 200 mS/m is usually considered unfit for land application due to high salinity. The water well at Fikolwa would therefore be considered to have a salinity problem.

Sodium Adsorption Ratio (SAR) is considered to be a better indication of potential sodicity problems that could develop during irrigation than the sodium content of the water as such. Water with a SAR higher than 5 is considered to be unfit for irrigation. SAR values of the water sources at all locations except Kanchele-well 3 are higher than 5, indicating that sodicity problems may develop in soils if provision is not made for adequate drainage to leach out the sodium.

The high SAR values are not caused by high sodium levels, but by very low calcium and magnesium levels. SAR values of water from the wells in Fikolwa and Mudobo Dambos are the highest of the wells tested. In the previous section it was indicated that there are

signs that relatively high ESP levels are developing in the soils of these Dambos. This situation calls for the development and implementation of innovative management strategies. On the one hand, ditch drains can be used effectively to provide leaching during the rain/flood season. On the other hand, this may cause dessication of the Dambos. One could look at opening ditch drains during the first part of the rain/flood season and then closing off their outlets to the river to collect water in the Dambo water table for the following dry season. Addition of gypsum could also be used to lower the effect of high SAR and to replace the sodium from the soil's exchange complex before leaching.

High exchangeable sodium is manifested by a dispersed (deflocculated) clay system which greatly reduces both air and water entry into the soil. A deflocculated soil without structure can easily be compacted and would form hard pans in the soil profile. In the previous section it was shown that Dambo subsoils have very high bulk densities. However, sandy soils, as are found at Fikolwa and Mudobo, are correspondingly less affected by increasing sodium on the exchange complex because of their low clay content.

From the results salinity does not seem to be a problem, except in the borehole at Fikolwa. Sodicity (high SAR) seems to be the danger.

3.1.5 Suggested Key Modifiers for Dambo Classification

Modifiers presented in Table 8 are essentially a development of inventories of Dambo attributes. To avoid professional bias in the classification, these attributes, as far as possible, are based on numerical expressions. As these modifiers are effectively wetland attributes they have been defined to avoid subjective interpretation. The approach is by no means "full-house" but could be revised in view of new advances. It is based on the U.S.

Department of the Interior system for classification of wetlands in which a basic description is extended through the use of so-called modifiers (Cowardin ***et al***,1979).

The features that all Dambos share is that they exist in headwater catchments and their soils are periodically saturated, usually as a consequence of impeded drainage arising from heavy textured subsoils and the low slope angles which reduce throughflow efficiency. Since there is little to be gained by protracted analysis of the exact definition of a Dambo, and there are numerous variants on the theme, a simple definition, which is both comprehensive and inclusive of the salient features without being too restrictive, is suggeted.

The modifiers presented in Table 8 should be viewed as a first attempt to introduce more scientifically rigorous definitions to Dambo **"types"** although it is possible that the modifers may need to be revised in the light of future findings (M^{c}Cartney and Daka, 1998).

Table 8: Key Modifiers for classification of Dambo types

	Modifiers	Description
Location	Source Valley	Dambo contains the source of a stream may or may not have a well defined channel in the valley bottom. Water input to the Dambo is predominantly rainfall and inflow from the surrounding interfluve. Dambo lies either side of a well defined stream channel at least 2 km from the start of a well defined stream channel. A component of the water into the Dambo during the wet season may rise from the overtopping of stream banks.
Period of saturationPeriod of saturationPeriod of saturation	Wet Dry	In most years of average or above average rainfall, the soil profile at seepage zone remains saturated to within 10cm of ground surface for greater than half the dry seaosn. In most years of average or above average rainfall, the water content of soils at the seepage zone at depths greater than 10cm below the ground surface decreases below saturation before half the dry season is over.
Soil chemistry	Sweet Intermediate Sour	pH of surface soils at the centre of the Dambo (i.e. valley bottom) is greater than 7.0 in August+. pH of surface soils at the centre of the Dambo (i.e valley bottom) is 5.6 - 6.9 in August. pH of surface soils at the centre of the Dambo (i.e valley bottom) is less than 5.5 in August.
Slope	Low Medium Steep	Average slopes from the valley bottom to the seepage zone are less than 0.5%. Average slopes from the valley bottom to the seepage zone are greater than 0.5% but less than 4%. Average slopes from the valley bottom to the seepage zone are greater than 4%.
Use	Cultivated Grazed Non-utilized	More than 10% of the Dambo is used for garden (dimba) cultivation. Dambo is used for grazing and/or stock watering. Dambo is not utilized for grazing and cultivation is less than 10%.

3.1.6 Examples of Dambo Classification:Classification of Fikolwa and Mudobo Dambos

The following attributes apply to the two Dambos as presented in Table 9. Quantitative and qualitative information on Dambo morphology, hydrology, soil chemistry and utilization data, as obtained from the field results presented in the previous sections, was used. Based on these, the following attributes are characterized for the two Dambos:

Table 9: Attributes of Dambos at Fikolwa and Mudobo.

Dambo	**Location**	**Stream flow**	**Wet/Dry**	**pH**	**Slope**	**Dambo use**
Fikolwa	Source	yes	Wet	4.7	0.0 - 0.5%	Non-utilized
Mudobo	Source	No	Dry	5.7	0.5 - 1.0%	Cultivated/grazed

From the foregoing the two Dambos are classified as follows:

A. **"Fikolwa is a wet non-utilized sour source Dambo"**

Note that non-utilized does not preclude the use of the Dambo but indicates limited use up to 10% of the Dambo area because of inherent limitations such as wetness and acidity. In this study it was found that only up to 5% of Fikolwa had actually been utilized.

B. "Mudobo is a dry medium grazed and cultivated intermediate source Dambo."

Mudobo Dambo is essentially an upland Dambo which farmers use for dry season cattle grazing. When water tables recede appreciably, farmers use hand dug wells to access water for irrigation of vegetables.

3.2 Long-term Land Use Changes In Dambos and Their Catchments

Land use in Dambos pertains to the cultivation practices, cattle grazing activities, clearing of land in the catchment for agricultural development and settlement of people. Many reasons abound for the changes in Dambos and their catchments. This section gives an analysis of human activity and climatic factors as they have affected Fikolwa and Mudobo Dambos.

3.2.1 Research Procedures

Information from some farmers who have been in the areas since late 1960's, coupled with that obtained from field surveys and aerial photo interpretation, was revealing. Aerial photos with time intervals of ten to sixteen years were chosen in order to observe long-term changes in land utilization and any environmental effects utilization had.

By pairing the aerial photos for each time interval of ten years, i.e 1970, 1980 and 1991, for Mudobo Dambo and a time interval of sixteen/ten years i.e 1967, 1983 and 1993, for Fikolwa, stereoscopic analyses were made and air photo moisaic maps at a scale of 1: 250,000, depicting land use (upland fields, Dambo gardens) rivers, buildings, forests and grasslands, wet Dambo and roads. Using square grids within the mosaic maps with the help of a 1: 250,000 topographic map, the above attributes were characterized in terms of their extent within a given Dambo. The changes for each time interval were noted and these were combined with actual groundtruth information from interviews of key informants and transect walks across each Dambo.

3.2.2 Results and Discussion

3.2.2.1 Land Use Patterns at Mudobo and Fikolwa Dambos

Table 10 highlights some data regarding land use patterns in catchment and associated upland areas in Mudobo and Fikolwa Dambos and their changes over time.

Table 10: Land Characteristics in Dambos and their Catchments

Year	Catchment Area (Ha)	Wet Dambo Area (Ha)	Dambo Gardens (Ha)	Upland Fields (Ha)	Built Area and roads (Ha)	Forest/ grassland (Ha)
Mudobo Dambo						
1970	1 000	250	125	100	25	500
1980	1 000	225	25	175	125	400
1991	1 000	225	200	75	175	325
Fikolwa Dambo						
1967	1 200	125	0	6.25	318.75	750*
1983	1 200	100	275	50	450	325*
1993	1 200	75	300	150	450	225*

*** Covered by bush and grassland**

3.2.2.2 Vegetation Changes

It is evident from the results in Table 10 that there are signs of forest vegetation declining with time in both the study areas of Fikolwa and Mudobo Dambos. At **Fikolwa** Dambo land area under bush and grassland was 750 ha in 1967 but reduced to 325 and 225 ha in 1983 and 1993 respectively. This represents an annual rate of decrease of 3.3%. It can therefore be estimated that by the year 2023 all the trees in the catchment of Fikolwa Dambo will be cleared if their cutting goes on unabated.

At **Mudobo** Dambo there were 500 ha of land under forests in 1970 and 400 ha and 325 ha in 1980 and 1991 respectively. This shows that forest vegetation has been depleted at an annual rate of about 2%. At this rate, the catchment forest would be depleted by the year 2041.

The reasons for the deforestation and grassland clearing are common in the two study areas. Information from the aerial photos, coupled with map interpretation and interviews from farmers reveal the following:

1. Tobacco cultivation in upper catchment areas of both Dambos promotes the cutting of trees for fuel wood used in curing tobacco.
2. At various times, trees have been cleared for opening up new fields for cultivation of other crops like maize, sunflower, groundnuts etc. according to the well-known "slash and burn" technique.
3. Uncontrolled bush fires are responsible for the depletion of grassland bushes and some forest species. Fires are set up in order to hunt small animals and also to clear the bush for cultivation.
4. Cutting of trees for making charcoal is common in both areas.
5. Cutting of trees for timber and fuel wood for domestic purposes.
6. Trees are cut to make beehives from their bark in order to collect honey from them.

The 3% rate of deforestation at Fikolwa Dambo is largely due to the greater ease of clearing grassland bushes as compared to cutting of large forest trees at Mudobo Dambo.

The vegetation in the Dambo at Fikolwa is largely covered by hyparhennia grass inter-spaced with 'Ifinsa" trees - water indicators and surrounded by miombo woodland. At Mudobo Dambo, the surrounding vegetation in the catchment is that of mopane woodland. Mopane trees are often used for making beehives, making fibre for construction purposes and making charcoal.

3.2.2.3 Dambo Gardens And Upland Cultivation

Table 10 gives an indication that there were virtually no Dambo gardens at **Fikolwa** in 1967 but sixteen years later in 1983, a sharp increase to 275 ha of Dambo gardens are evident in both the wet and dry Dambo areas. According to farmers' responses to the interviews, the absence of gardens in 1967 at Fikolwa was partly due to heavy flooding and frost occurrence in the winter months of July and August.

Table 10 further supports these views with values showing the presence of large wet areas (125 ha). Evidence from this study also reveals that major parts of Fikolwa Dambo are acidic in nature and thus utilization is restricted or requires sound management practices for proper soil amelioration. However, 5% of the Dambo, including outlet stream banks which stretch for over 1 km are used for cultivation of vegetables and nurseries for tobacco seedlings. The latter is the reason for a larger area under Dambo gardens (275 ha) in 1983 than the actual wet Dambo area of 100 ha in extent.

Note that the progressive decrease of wet Dambo areas from 125 ha (1967) to 100 ha (1983) and 75 ha (1993) is associated with slight increase in Dambo gardens from no gardens in 1967 to 275 ha (1983) and 300 ha (1993) - an indication of flood recession. Between 1983 and 1993 the further increase in area under Dambo gardens at Fikolwa was very small, only from 275 ha to 300 ha. Thus the rapid increase of 17 ha per year observed in the first sixteen years dropped to an increase of only 2 ha/year over the ten year period of 1983 to 1993. This may signify that almost all households may have accessed Dambo land.

Farmers allude to the fact there were five villages in 1967 as compared to seven and nine in 1983 and 1993 respectively. This conforms to the information in Table 10 wherein the built area and roads coverage remained constant at 450 ha between 1983 and 1993.

It would appear that there is a relationship between reduced rainfall and wet sites in Dambo areas, asone would expect. High rainfall favoured upland cultivation as opposed to cultivation of Dambos. This is logical, since high rainfall will enable successful rainfed cropping in upland areas, while Dambos will be subject to flooding. Conversely, reduced rainfall is associated with with reduced wet sites (little or no flooding) in Dambos and thus favourable conditions for Dambo gardens whereas upland rainfed crops will suffer drought stress during such seasons. This is best illustrated by the sharp increase in area under Dambo gardens and sharp reduction in upland fields at Mudobo Dambo in 1991 when annual rainfall was at the extremely low level of only 550 mm.

The increased use of Dambo gardens can, apart from poor rainfall affecting upland fields, be attributed to the expansion of the village community population due to the advent of schools, hospitals, churches and post offices which have since attracted the settlement of many villages.

The liberalization of the economy to a free market and Government's decision not to be involved in marketing of the staple and other cereals, and removal of Government subsidy on agricultural inputs which supported the growing of upland cash crops, saw reduced cultivation of these crops and forced a shift to staple maize and vegetable growing in gardening as a way of coping with food insecurity. This policy change was well-meant,

but its practical implementation is fraught with many problems, as was also clearly outlined by Kwa-Mensah (1999). These factors coupled with rainfall as a major determinant of cropping in Dambos and upland fields are important, particularly at Mudobo where upland cash crops were grown by many farmers. It is noticeable at Mudobo that the shift from cash crops to staple maize in upland areas also reflects on the adoption of Dambo gardens.

3.2.2.4 Trends in Land Areas Covered by Wet Dambos

Figure 9 indicates that rainfall at Fikolwa Dambo was low the whole period of 1989 to 1991. The 1991 season itself had very low rainfall and saw the entire Southern Africa hit by the worst drought in human memory on the continent of Africa. There appears to be a lag recharge period because 1993 despite being a high rainfall year at Fikolwa, still had reduced wet Dambo areas, showing the effects of the previous dry years which may have lowered the water tables tremendously.

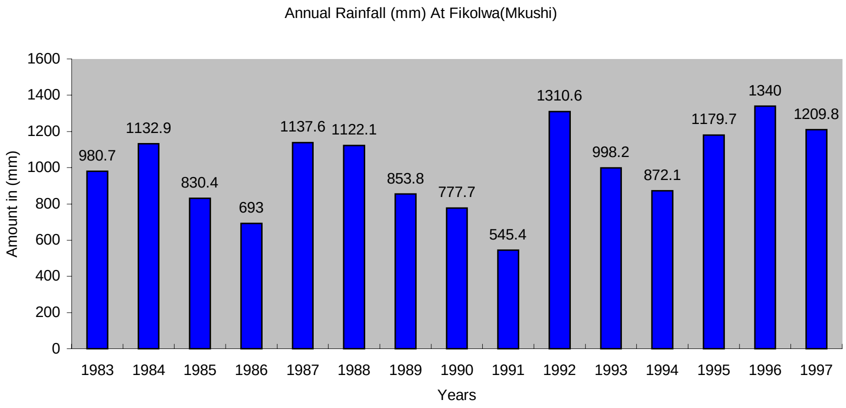


Figure 9: Annual rainfall totals at Fikolwa

Table 10 indicates that in general terms, there has been a slight decrease in the wet areas of both Dambos. Mudobo Dambo shows an average annual decline of about 1% between 1970 and 1980, after which there was no further decline.

At Fikolwa Dambo the average annual decrease in wet Dambo area from 1967 to 1983 was about 1.5%, after which it decreased by about 2.5% per annum between 1983 and 1993. The latter decreases are alarming and could possibly be attributed to the much bigger degree of deforestation at Fikolwa than at Mudobo. Deforestation in the catchment area seems to have had negative effects on the recharging of the Dambo, enforcing an overall dessication of the main Dambo.

Farmers at both locations attribute the reduction of Dambo land to drying as a result of poor rainfall over the years. M^{c}Cartney and Daka (1998) quote Grant (1995) as follows: ***"The cropping potential of the Dambos results from the availability of water to crops, especially during periods of mid-season drought. It does not result from inherent nutrient availability."***

It would appear that the larger areas of Dambo gardens than actual wet Dambo area is supported by the existence of widespread seepage zones and good aquifer recharge with shallow water tables from which hand dug wells would support appreciable sizes of gardens.

3.2.2.5 Erosion

Erosion was not evident in either Fikolwa or Mudobo Dambo. However, the upland areas in the catchment of Mudobo showed evidence of soil being dislodged by cattle foot tramping along small tracks. This soil can be easily carried away by rain and is normally deposited in Dambos or streams. The upland areas of the Mudobo catchment also have some gullies formed in places of poor drainage, with petroplinthite impeding water entry into the soil and confining it in small channels formed by human activity or cattle. Farmers recognize the fact that overgrazing in the Dambo would cause erosion. At Fikolwa, both the upland and Dambo are free from erosion. Upper catchment areas with deep sandy soils promote infiltration of water and sub-surface flow to recharge lowland areas, particularly the Dambo itself. The effects of catchment deforestation on erosion and the benefits gained by planting trees on degraded and eroded catchments will be dependent on the situation and the management methods employed. However, afforestation itself is not a quick panacea since one needs to know the type of tree species to plant. Other remedies would include the following:

1. Erosion control using contour bands re-enforced with vertiver grass on steep slopes.
2. Reduce or stop indiscriminate cutting down of trees in the catchment area by planting fuel wood plantations in the watershed area. The programme can set up agro-forestry nurseries in conjunction with rural communities and NGOs.
3. Advise farmers not to overgraze their land by not overstocking.
4. Protecting catchment and Dambo vegetation from indiscriminate bush fires.
5. Cultivating across the Dambo slopes in order to arrest the problem of siltation of river and dams.

3.3 CONCLUSIONS

1. Rainfall has a major influence on the land-use changes in Dambos and their upland rainfed fields: Firstly drought years cause prolonged dessication of Dambos, with a good rain season showing a lag time of recharge. Secondly, Dambos act as safety-nets during such drought periods because of their moisture storing potential and less upland fields are used. A good rain season with flooding hazards sees less utilization of Dambos than upland fields which are free from flooding.

2. The above classification reveals some of the ground truth information at Fikolwa where vegetables are difficult to grow. This can be due to soil acidity, particularly in the central/seepage zones where the topsoil pH value was 4.7. Vegetable species tolerant to soil acidity should be identified and grown in this Dambo if it has to be fully utilized (see Table 12 in Chapter 4). Other crops will do well in the rain season, when it is expected that soil pH will be high, provided that flooding will not damage them. Planting on ridges may help. Mudobo Dambo on the other hand would support a wider range of vegetables on account of absence of high soil acidity in topsoil.

3. Acidifying nitrogen fertilizers and excessive nitrogen application must be avoided. Limestone Ammonium Nitrate could be the preferable choice.

4. Less tolerant crops to soil acidity are cabbage, rape, broccolli, cauliflower, chinese cabbage, lettuce, Okra and bulb onion. These will flourish within a pH range of 6.0 - 6.8. This range is most likely to occur in the transition and upper grassland zones of most Dambos. Use of a treadle pump to lift water to gardens in these zones is a must.

5. Use of animal manure at Mudobo is a major source of phosphorus.

6. Water sources from the two Dambos are shallow wells which do not dry up easily. At Fikolwa water from the stream is used for river bank gardening at the outlet.

7. Gradual slopes towards the central zones allow for steady deposition of nutrients from the surrounding high ground. This adds to the fertility status of the soil.

CHAPTER 4

UNDERSTANDING DAMBOS: A FARMER PERSPECTIVE TOWARDS SUSTAINABLE CROP PRODUCTION

4.1 Background

The preceding chapter demonstrated the importance of Dambos as key environmental resource areas that act as socio-economic safety-nets for bridging the hunger gap and providing food at household level. On account of this, they need to be exploited in a sustainable manner. Dambo study reviews have established these environments as being complex in nature and requiring multidisciplinary research to understand them better. This chapter analyzes farmers'experience and synthesizes them with empirical findings of this study in order to make the understanding from a single qualitative perspective. Dambo land use, folklore and myths are discussed from a scientific standpoint.

Variations of water table depths in the upper grassland, seepage, transition, lower grassland and central Dambo zones, were monitored as described in Section 2.4. The water movement, storage and fate in the various Dambo zones was understood by analyzing the collected data which was treated against the prevailing precipitation and evapotranspiration as collected from the weather station to produce Figure 10.

A socio-economic survey was conducted using a Participatory Rural Appraisal (PRA) involving a sample of some farmers cultivating Dambos for crop production (see Section 2.2). Using the hydrological results, coupled with farmer practices and constraint analysis, crop calendars were developed and recommendations made for best practices.

4.2 Results and Discussion

4.2.1 Precipitation and Dambo Hydrology

From farmers' perspectives of long-term use of Dambos, they have well understood Dambo hydrology. Years of droughts and good rainfall have affected Dambos by drying and recharging respectively. However the drying is understandably superfluous in that water is usually available within 1-3 m depth from the soil surface. This study has monitored water table variations resulting from rainfall input and evaporation. The observations so far suggest that precipitation is a major contributor of Dambo recharges. Folklore and myths suggest that vegetation removal reduces rainfall but farmers found that despite widespread vegetation removal for fuelwood and replacement with annual crops such as maize and vegetables in Dambos and their catchments, rainfall did not change and in fact Dambos recharged.

These observations were confirmed by farmers from the Eastern and Northern Provinces of Zambia where tree cutting is rampant. In the Northern Province, the system of upland cultivation involves tree branch cutting, grass slashing and burning. This type of cultivation is called the **"Chitemene"** farming system. Dambo recharge has remained relatively unaffected despite vegetation removal. It would appear that the inducement of Dambo recharge after vegetation removal is chiefly due to reduced evapotranspiration from annual plants as opposed to tree crops which are often deep rooted. Evidence of water tables rising shortly after trees have shed their leaves is not uncommon. It is thus inferred that although not a panacea, forest vegetation removal and replacement by annual crops does help to recharge Dambos. Rainfall events however promote recharge in Dambos as seen in Figure 10.

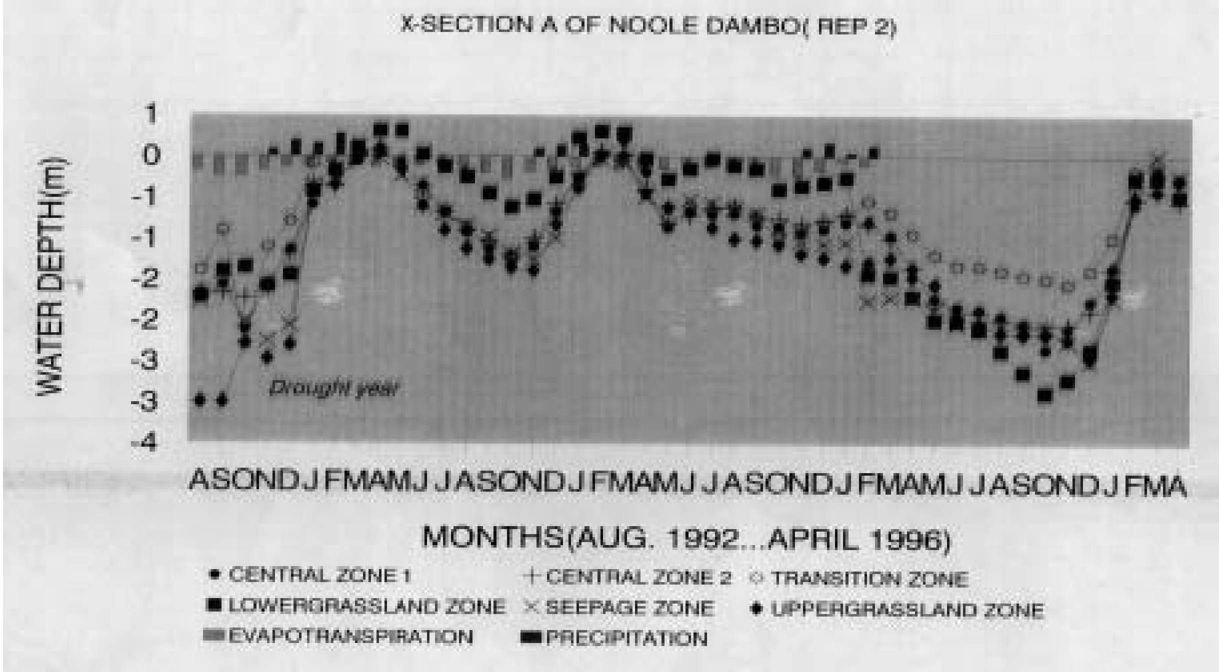


Figure 10: Variation of water table depths in Noole Dambo.

From Figure 10 it is evident that a quick response of water table recharge with respect to rainfall events exists. Depending on soil type in the Dambo, as well as sub-surface inflow from the interfluve, a time lag of one month may be experienced. However excessive evapotranspiration (direct evaporation and transpiration from vegetation) has an effect of lowering water table levels. Dambo interfluves that are largely covered by tree vegetation effect water table recession in the main Dambo system because of increased evapotranspiration.

Farmers' perception over several decades of Dambo use is that wetness is heavily affected by changes in rainfall intensity and distribution in space and time. They confirm that a good rain season is followed by a general rise in water tables in Dambos throughout the rain period. On the other hand, a drought year with excessive evapotranspiration causes early drying of Dambos. Farmers often have to dig their wells deeper to access the water

for irrigation and

livestock from the receding water tables. A normal rain season following a drought year recharges Dambos with water almost immediately. Farmers respond with increased cropping in Dambo gardens rather than abandoned gardens with disused fences which ensue and characterize a drought year.

Pereira (1989) suggests that forests are not generators of rainfall, yet this "Myth" like many others in forest hydrology may contain a modicum of truth that prevents it from totally being laid off to rest. Evidence from the present study suggests that there is no direct relationship between removed forest cover and decreased rainfall (see Section 1.5.1). Pereira (1989) concludes that much of this folklore is seen to be either exaggerated or untenable. Whereas there may be some limited increase in rainfall due to the presence of forest trees, this is almost always offset by increased transpiration, which leads to an overall reduction in water resources. Hence there is an observed reduction in groundwater levels in Dambos surrounded by trees. Meteorological theory indicates small increases in rainfall due to the orographic effect of tall trees that intercept some of this rain which is later re-evaporated and returns as rain but it never amounts to significant increases in rainfall.

The distribution of forest vegetation is a consequence of climate and soil conditions and not ***vice-versa*.** However a hydrologic relationship exists, with Dambos recharging after forest vegetation has been removed. Daka (1995) delineated Dambos into zones and agrees with Rattray's classification **(Rattray, 1953)** but characterizes these zones on the basis of field and empirical observations as shown in Table 11.

Table 11: Dambo characterization in terms of slope, water table and crop production limitations.

Zone	Characterization of water table	Slope	Specific limitations
Upper grassland	Water table is usually between 20 – 70 cm in the rain season and1 - 2 m in the dry season.	0-1%	The dry season may promote water shortages and salt accumulation in root zone. Some difficulties to lift water using bucket when water table is quite deep. Use of manual lift devices is advised.
Transition/ Seepage	Water table usually at surface level and above in the rain season. Lies at between 40cm above the surface in the rain season and 50 cm below the surface in the dry season.	1 -1.5%	Excess water becomes runoff downstream. Capillary rise water often meets crop water requirements in the dry season and in the rain season, when flooding is common, special crop adaptation is required for proper growth.
Lower Grassland	Has intermediate attributes of the Upper grassland and Transition zones	0.5-1%	Root zone often saturated, but with natural outflow to the Central zone. Planting on raised beds is recommended for good crop growth.
Central	Water table usually is between 10-50 cm above the surface in the rain season and 50 cm below the surface in the dry season.	0-1%	Excess water impairs crop growth. Crops grown on raised beds, which provide good drainage and aeration.

Water tables rise sharply following an event of rainfall but also begin to recede at the cessation of the rain season when trees are still at a vegetative stage. The Seepage zone supports widespread growing of vegetables for most part of the dry season due to high water tables that effect capillary rise. Farmers'gardens are usually concentrated in this zone as not much effort or skill is needed to control or manage water to irrigate crops.

During the rain season, flood injury to crops may occur, so farmers shift their gardens to the upper grassland zones which are well drained as a result of deeper water tables. Shallow wells are dug to a depth of 2-3 m to access the water for irrigation. Lifting such water may require use of a water-lifting device as opposed to the present use of a rope and a bucket, which is tedious. Figure 11 shows how farmers cope with variations of water tables and difficulties of water application in Dambo gardens. In the rain season and also in very wet Dambos during the dry season, farmers grow crops on raised flat ridges and beds in order to restitute a normal root zone with good drainage and aeration for proper crop growth. Farmers also impound water in between the beds and use this to scoop the water for supplementary irrigation. In the event of using a water-lifting device, these buffer ponds from impounded water act as sources of water (Figure 12).

Figure 11: **Scooping water from furrows between flat beds and watering crops with a bucket**

Normal rooting depth for vegetables is 30-60 cm. Thus it follows that the flood level in any Dambo zone will determine the height of the ridge. The beds are raised to a height of 50-100 cm so as to effect capillary rise from the height of water that collects in furrows between the ridges and beds. If capillary rise is inadequate and/or the plant roots are too shallow to access water from the wetting front, farmers scoop the water with buckets and apply it on the crop simulating rainfall to supplement the crop with water.

Ridge heights of 50-100 cm are common in the rain season but are destroyed in the dry season to ensure planting is done on flat ground following the receding water table and taking advantage of capillary rise. During the rain season most parts of Dambo gardens are used to grow an early maize crop (planted at the end of the dry season between August and October) of which much is harvested and sold as green cobs. With the exception of a few farmers, vegetable production is restricted to the dry season by most farmers. This is due to the risk of flooding and occurrence of pests and diseases during the wet season.

Figure 12: Raised beds with impoundment water ponds for irrigation.

4.2.1.1 Precipitation versus run-off in Dambos

Because of their wet conditions for most part of the year, Dambos produce more run-off from rainfall and less evapotranspiration than surrounding high ground throughout the rain season (Daka, 1993). It was found that the woodland catchment had infiltration rates ranging from 30-50 mm/hr at Noole Dambo as compared to 3-5 mm/hr in the Dambo central parts where clay soils were dominant. The catchment of a Dambo and its margins had more vegetation cover and was covered with light sandy soils with a larger aquifer than the Dambo itself. In this way more groundwater was stored in the woodland catchment area. This is responsible for late season stream flow when vegetation is

removed and replaced with annual crops. The inference here is that the Dambo generates more surface run-off while the woodland contributes more ground water component during the rain season. Robinson, Moore and Blackie (1997) indicate that drainage activities associated with forests increase dry season flows. Evidence from South Africa point to the fact increased dry season transpiration reduces both dry season and annual stream flows (Bosch, 1997).

From a theoretical standpoint, it would appear that increased transpiration and increased dry season tranpiration will increase soil moisture deficits and thus reduce dry season flows. Increased infiltration that occurs in vegetated upper margins of Dambos, will lead to higher soil water recharge and increased dry season flows. This view seems to support the myth that **"Forests Reduce Erosion".** This common wisdom appears to hold water on account of the following factors;

1. The high infiltration rates in natural woodlands of Dambo catchments reduces the incidence of surface run-off and thus reduce erosion. Farmers do note that the existence of sandy soils in Dambo margins promotes infiltration and sub-surface flow of water rather than run-off, and that this reduces erosion.
2. The reduced rainfall impact and run-off and the binding effect of tree roots enhance slope stability, which tends to reduce erosion.
3. On steep slopes, forestry or agroforestry may be a sustainable solution where conventional soil conservation techniques and bunding may be insufficient to contain mass movement of soil.
4. Land use practices such as cultivation, drainage, road construction, road use and felling trees increase erosion.

4.2.2 Dambo Attributes and Characteristics

Dambos as resource areas possess different attributes and characteristics worth exploiting agriculturally. Scoones (1992) observed a number of common features of Dambos. The present study, following a participatory rural appraisal of Dambo environments, found that the farmers are aware of these features. The following attributes and characteristics of Dambos are noteworthy;

1. Areas that act as drainage pathways or sinks for the surrounding dryland catchment.
2. Areas with higher levels of soil moisture than the surrounding upland during the dry season and in drought periods.
3. Depositional areas where organic matter and soil nutrients accumulate, making the soil richer than the surrounding top land.
4. Areas that are generally small in relation to overall available area but have the potential for extended seasonal use and provide opportunity for diverse usage.
5. Areas that are often key components in sustaining rural livelihoods, both in agricultural and pastoral systems as complement to upland dry land use.

On account of these observed attributes and characteristics, farmers have identified Dambo soils to be inherently rich in plant nutrients and thus do not require much additional fertilizer whenever needed. Most farmers have observed a good crop response without any additional inputs to grow them. They generally describe Dambo soils to be highly fertile.

Soil fertility may be defined as the ability of the soil to provide physical conditions favourable to root growth and to supply enough water and nutrients to enable a crop to make the most of other environmental features of a site.

4.3 Dambo Chemistry

The study has identified a number of Dambos with similar attributes but sometimes different from one another in terms of chemical and hydrological conditions. Observations and soil analyses are compatible with those of Verboom (1970). On the basis of these findings, Dambos have been classified into three categories as follows;

(i) ***Sweet Dambos***
(ii) ***Intermediate Dambos** and*
(iii) ***Sour Dambos**.*

The classification is primarily based on soil pH and vegetation. The respective Dambo types are described as follows;

4.3.1 Sweet Dambos

Sweet Dambos are found on soils developed from basic rocks and have a pH higher than 6.5. Vegetation and soils characterize these environments well. Most farmers are utilizing these Dambos for grazing and crop production. Sweet Dambos are the most exploited by the small-scale farmers in Zambia. A number of crops do well in such Dambos as they are adapted to the neutral to alkaline pH levels that prevail. Because of optimal pH levels, a number of shrub and grass species that flourish here are palatable and highly nutritious for grazing livestock. Farmers grow vegetable crops and graze their cattle in these Dambos. To do both activities at once, the vegetable gardens are fenced off for protection from cattle or the cattle are looked after during grazing by a care taker. Farmers perceive Dambos that are less grazed by cattle as being sour or acidic and thus avoid them for crop production.

4.3.2 Intermediate Dambos

Intermediate Dambos have soils developed from mixed sediments with a pH between 5.5 and 6.5 and have a wide range of vegetation species with mixes of palatable and some unpalatable species for cattle grazing. Such Dambos are prevalent on the Zambian plateaux and are moderately used for crop production and animal grazing. Farmers use only selected parts with good soils and water for vegetable gardening while areas with little or no water and with poor soils/pasture are used for grazing. Farmers perceive Dambo areas with Fig trees and Msinyika tree (Syzygium cordatum) as areas with very good water sources at shallow depths from the ground surface.

4.3.3 Sour Dambos

Sour Dambos are common in the high rainfall northern half of Zambia which experiences excessive leaching of soils. Soil pH in these Dambos is below 5.5 and so they are strongly acidic in nature. Such Dambos are not good for cattle grazing as most grass species found here are unpalatable and have low nutritional value. Crop production requires special management practices such as selecting acid tolerant crop species or judicious liming. Small-scale farmers know through experience what crops are better suited to different types of Dambos. Soil pH in a Dambo may vary with seasons, becoming more acidic in dry seasons (pH=4.5) than during rain seasons (pH=6.0). Raussen *et al.* (1994) reported that farmers usually burn grass in sour Dambos to allow regeneration of fresh grass of which some are palatable for cattle grazing. To some extent plant ash also acts as a liming agent. Through experience farmers have come to know crops which like growing in burnt spots within a sour Dambo. These include pumpkins, beans, cucumber and irish potatoes.

4.4 Dambo Cropping

Dambos manifest different levels of soil fertility and thus differences in crop responses to soil acidity are observed. Table 11 for example outlines the types of crops that do well in different types of Dambos as identified by farmers in the field. Their identification of crop suitability was matched with soil pH prevailing in those soils. Using this indigenous knowledge and matching it with technical know-how (i.e considering nutrients, soil pH and flooding hazard) recommendations for crop adaptability in Dambos have been derived, such as growing crops on high ridges to avoid flood damage, providing aeration in root zones will allow proper decomposition of organic matter, raise pH and thus making most soil nutrients available to crops. Burning of vegetation whilest being beneficial through having a liming effect and acting as fertilizer, should be timed early in the dry season. Acid Dambos should not be burnt later than the month of May to avoid severe fires that will lead to loss of nitrogen in the plant biomass. If these are accidentally burnt by people who hunt small animals for food, then kraal manure should be added before planting a crop.

Common wisdom and indigenous knowledge points to the fact that very sandy Dambo soils are weakly buffered and tend to be strongly acid in nature due to excessive leaching and thereby posing a range of fertility constraints.

Table 12: Low pH tolerance of various vegetables

Slightly tolerant (**pH 6.0- 6.8**)	**Moderately tolerant** (**pH 5.5-6.8)**	**Very tolerant** (**pH 5.0-5.5)**
Cabbage	Tomato	Irish Potato
Spinach	Bean	Sweet Potato
Rape	Carrot	Rhubarb
Broccoli	Pumpkin	Shallot
Cauliflower	Squash	Water Melon
Chinese Cabbage	Cucumber	
Lettuce	Eggplant	
Okra	Garlic	
Onion	Mustard	
	Pea	
	Green Pepper	
	Radish	

(source: Raussen, Daka and Bangwe, 1996).

Crop failure, which some farmers have attributed to soil wetness in Dambos, could in some cases be caused by soil acidity or a combination of the two. Noole Dambo soil analysis shows some differences of soil pH in different zones and at various soil depths in the same zones as indicated in Table 13. Effects of anaerobic soil conditions due to waterlogging are manifested through yellowing of plants due to a nitrogen deficiency. Sometimes losses of applied inorganic nitrogen occur by denitrification, particularly if the soils are saturated immediately after fertilization. Attention to good drainage (use of high ridges or cropping in upper grassland zones) and aeration often results in net positive effects of applied nitrogen. Purple colour in crops has also been observed under waterlogged conditions. This is due to a phosphorus deficiency (Figure 13).

Figure 13: Plant phosphorus deficiency in cabbage grown at Indaba Dambo (Chipata).

Plant nutrient balance and supply is generally more favourable in soils with a moderately high clay content (Gleysols, Vertisols) and a high level of well decomposed organic matter, both of which provide colloidal exchange sites for the major plant nutrients. However, when under continuously wet conditions, Dambo soils frequently accumulate poorly decomposed organic matter (peats and mucks) and are strongly leached with low pH (high acidity). Under strongly acid conditions there may be deficiencies in plant available nitrogen, phosphorus and/or molybdenum and/or toxic levels of aluminium and/or manganese. This study observed that the organic matter content of Dambo soils was usually several times higher than that of upland soils, but often not as well decomposed (see section 3.1.2.2).

Table 13: Soil pH in different zones and soil depth for Noole Dambo

Soil depth (cm)	Upper Grassland zone pH ($CaCl_2$)	Transition zone pH ($CaCl_2$)	Seepage zone pH ($CaCl_2$)	Central zone pH ($CaCl_2$)
0-20	5.57	4.75	5.89	6.56
20-40	5.63	4.73	5.85	6.54
40-60	5.66	4.54	5.76	7.08
60-80	5.53	4.81	6.58	7.12
80-100	5.72	4.90	6.44	7.15

The data in Table 13 indicate that the lower lying zones have more nutrient reserves and higher pH values than the upper grassland/transition zones. This is due to lateral subsurface transport of dissolved bases and other nutrients from higher lying zones and their accumulation in these sink zones where the water collects. This is an often underestimated phenomenon of major proportions in many tropical and sub-tropical toposequences. At high pH values a wide range of crops grow well. It confirms the well-known relationship between soil pH and soil fertility. Kandela (1993), for example, mentioned the well-known relationship between low pH (pH = 4.5 - 5.0) and low base saturation percentage as well as low cation exchange capacity. On the other hand, at a high pH such as 6.5 and above, a base saturation percentage of 100% and a cation exchange capacity of 33 $cmol_{(+)}$/kg are not uncommon.

Given the pH levels at Noole Dambo and taking into account farmers' experiences, the following vegetable types can be grown in its different zones as presented in Table 14.

Table 14: Suggested vegetable types to be grown in various zones of Noole Dambo

Dambo zone	**Recommended vegetable types to be grown**
Upper grassland zone	Tomatoes, Beans, Eggplant, Green pepper, Pumpkin, Carrot, Cucumber.
Transition zone	Water melons, Maize, Irish potatoes, Shallots.
Seepage/central zone	Cabbage, Rape, Cauliflower, Okra, Onion, Lettuce, Maize, Spinach, Chinese cabbage.

4.4.1 Flood Injury to Crops in Dambos

Flood damage can be in the form of direct physical damage to crops by the fast flowing water. It can also be in the form of crops being covered by transported soil which settles out when the flood subsides. "Indirect" flood damage, associated with reduced plant growth, chlorosis (yellowing of leaves), senescence and death, is common in flooded agricultural lands. When free oxygen in the soil is exhausted during waterlogging, microbes resort to other substances in the rhizosphere as electron donors in place of oxygen and as a consequence the rhizosphere becomes more anaerobic (lacks oxygen). Phytotoxic products such as nitrites, ferrous ion, sulphides, and manganous ions are produced due to reduction processes of nitrates, ferric ions, sulphates and manganic ions respectively. In some cases plant roots themselves produce toxic substances, like cyanides, under waterlogged conditions.

Flooding is often aggravated, both in terms of intensity and frequency, by land mismanagement in catchments. Reduction of the vegetative cover in a catchment, due to overgrazing or over-exploitation of the vegetation for firewood or construction can, for example, greatly enhance runoff and aggravate flooding.

From farmers' standpoint, floods can be both a blessing and a curse. A blessing in that as they try to cope with them by digging trenches in the upper slopes of the Dambo margin/transition to arrest any possible surface run-off, they harvest this water which proves useful for dry season cropping as it recharges the Dambo itself.

Another strategy is where farmers plant on high ridges to avoid flood injury. For some crops, like maize, farmers will plant early at the end of the dry season in August so that the crop is well established at the onset of the rain season. In this way the crop would be well above the flood level not be sub-merge. The flood recession has also been utilized by farmers. In some areas farmers plant crops like maize behind a receding flood at the end of the flood season to exploit the water stored in the soil. They refer to this system which utilizes residual moisture without any supplementary application of water as **"Zilili"**.

At the University of Fort Hare in South Africa Prof. J.N. Marais simulated this by filling a soil to field capacity with a flood irrigation before planting and comparing it with normal dryland cropping. He gave no further irrigations during the season. The normal dryland maize died from drought before Christmas. The maize planted on a full profile and which after that had to survive on the same rain, did not only survive, but yielded 8.5 tonnes per hectare (Laker, 2001; personal communication).

4.4.2 Crop Calendars Developed by Farmers

The Participatory Rural Appraisal (PRA) survey revealed that while crops grown in different Dambo areas were similar, they were planted at different times of the year. Reasons for different timings vary from flood injury escape, disease avoidance to marketing of Dambo produce. For example maize planted in August does not only escape drought at the onset of the rains during November/December but is harvested and sold as fresh at high prices since it comes as an off-season crop. At this time there is an easy market since it coincides with high demand in the month of December. Similarly tomatoes are planted on upper zones of the Dambo and on ridges around in August to coincide with high prices in December through to March. However, this window period is the most difficult time to grow tomatoes because of associated diseases. Tables 15, 16 and 17 show cropping calendars, intensities and cultural practices for their management as developed by farmers at various Dambo sites.

Table 15: Cropping calendar at Chipala Dambo in Agro-ecological zone III

CROPS	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
1. Cabbage	*	*	*	*	*	*	*	*	*	*	*	*
2. Maize								*	*	*	*	*
3. Rape	*	*	*	*	*	*	*	*	*	*	*	*
4. Tomatoes				*	*	*	*			*	*	*
5. Water melons	*	*	*	*	*	*	*	*				
6. Bulb onion				*	*	*	*	*	*	*		
7. Okra				*	*	*	*			*	*	*
8. Beetroot			*	*	*			*	*	*	*	*
9. Carrot				*	*	*	*	*	*			
10.Irish potatoes				*	*	*	*	*			*	*
11. Beans				*	*	*	*	*			*	*

Table 16: Cropping calendar at Siachitema Dambo in Agro-ecological zone II

CROPS	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
1. Cabbage	*	*	*	*	*	*	*	*	*	*	*	*
2. Maize	*	*	*	*	*			*	*	*	*	*
3. Giant Rape	*	*	*	*	*	*	*	*	*	*	*	*
4. Tomatoes				*	*	*	*			*	*	*
5. Cauliflower	*	*	*	*	*	*	*	*				
6. Spring onion				*	*	*	*	*	*	*	*	*
7. Paprika	*	*	*	*	*	*	*	*	*	*	*	*
8. Green pepper			*	*	*	*	*	*	*	*	*	*

Table 17: Cropping calendar at Musofu Dambo in Agro-ecological zone I/II

CROPS	J	F	M	A	M	J	J	A	S	O	N	D
1. Cabbage	*	*	*	*	*	*	*	*	*	*	*	*
2. Maize							*	*	*	*	*	*
3. Giant Rape	*	*	*	*	*	*	*	*	*	*	*	*
4. Tomatoes	*	*	*	*	*	*	*	*	*	*	*	*
5. Cauliflower				*	*	*	*	*				
6. Spring onion				*	*	*	*	*	*	*	*	*
7. Paprika	*	*	*	*	*	*	*	*	*	*	*	*
8. Eggplant	*	*	*	*	*	*	*	*	*	*	*	*
9. Peas	*			*	*	*	*			*	*	*
10.Impwa	*	*	*	*	*	*	*	*	*	*	*	*
11.Irish potato	*	*	*	*	*	*	*	*	*	*	*	*
12. Green pepper		*	*	*	*	*	*	*	*	*	*	*

4.4.1.1 Land preparation

In nearly all the Dambo areas, land preparation begins at the end of the rain season during April. Hand hoes are used in most cases, except in Southern province at Siachitema Dambo where ox-drawn ploughs are commonly used. Both these methods are appropriate as they do not require draining of the Dambo. Depending on the water level, ridges and raised flat beds are prepared. When planted on the flat ground (without ridges or raised beds), small channels for simple drainage within the Dambo are made. Crops like tomatoes and cabbages are planted in nurseries and transplanted later around May/June. Other crops are directly planted in the field and thinned to the required spacing. During land preparation, grasses or rice stover from previous crops are worked in and allowed to decompose for fertility enhancement of the soil.

4.4.2.2 Diversity of crops, timing of planting and marketing

The data in the previous tables indicate that Dambos support a wide range of crops. At Musofu and Chipala a larger variety of crops are grown than at Siachitema. Some crops grown include; cabbage, rape, tomatoes, peas, eggplants and watermelons, to mention but a few. The wide range of varieties is particularly because of the high demand for vegetables from the Copperbelt province. At Musofu in particular, tomatoes, green pepper, impwa and irish potatoes are grown throughout the year, indicating the economic importance in the livelihoods of the farmers and the community. In Luapula Province, particularly in Mwense, Kawambwa and Nchelenge districts, farmers have started growing indigenous vegetables in Dambos. Such local vegetables are only common during the rain season but command a high demand during the dry season when they are off-season. Certainly Dambos have accorded small-scale farmers to grow them during the dry season in Dambo gardens.

Most gardens are located in the seepage zones where soil moisture is in abundance. During the rain season, drainage within a Dambo becomes important. The local market mostly influences the timing of crops at the time of harvesting. However, glut occurs when all farmers plant the same crop at the same time and thus forcing low prices for their produce because of abundant supply.

Growing of crops during the rain season is difficult due to diseases. Control of such diseases is usually untenable by most farmers because they lack finance to purchase the chemicals. It is during this time that vegetables are scarce and that premium prices on the produce is characteristic. It was observed that the indigenous vegetables are quite resistant to most diseases and thus offers great potential for popularizing in Dambo cropping.

4.5 Potentials and Limitations of Dambos for Crop Production

4.5.1 Potentials

- Extended use of Dambos for crop production is possible even in the dry season and drought periods owing to their shallow water tables that make them remain wet/moist.
- Minimum inorganic fertilizer inputs need to be used in Dambos since they possess inherent high fertility as they are depositional areas or sinks of organic matter from surrounding high ground. Farmers understand this important aspect and apply it well to their advantage by not unduly applying fertilizer to their crop.
- Dambos usually absorb water from rainfall and this is stored in deeper sandy layers which are overlain by clay soils and thus acting as sponges that release water slowly even into the dry season for later use in crop production.
- Small- scale irrigation is possible in Dambos due to the prevailing hydrological conditions that allow for crop production in the dry season with capillary rise water and water drawn from shallow water tables for irrigation.
- Dambos are so widely and scatteredly distributed in space that they become accessible to the majority of small-scale farmers who are the main contributors to national food production.
- The relative abundance of water in Dambos does not call for great management efforts to distribute it.

- Excess water applied by way of irrigation returns to shallow water tables as recharge for later use.
- Most of the water required by plants is directly taken up from the capillary zone above the shallow water table. At other places, where water tables are too deep, pumping becomes critical in order to irrigate the crops.
- Dambos are also a source of wild fruits such as orchids and a good environment for indigenous vegetables that grow wild and become a source of relish.
- Dambos are used for hunting small animals and as grazing land for cattle.

4.5.2 Limitations

- Dambos may become flooded during the rain season or throughout the year, thus limiting their use for crop production unless special management practices are employed as coping strategies.
- Some Dambos become acidic in nature due to prolonged dry and wet cycles and thus special knowledge of crop suitability is essential.
- Heavy clay soils usually occur in the central zone due to clay translocation from the upper Dambo catchment and iluviation in the lower zones. These are difficult to cultivate and they limit the extent to which Dambos may be utilized with simple hand hoes as tools.
- Infiltration rates from the upper catchment may be impaired if deforestation occurs, coupled with overgrazing which might cause excessive erosion from run-off water.
- Dambos do not compromise their use between cropping and grazing unless the former is preceded by fencing the gardens.

4.6 Farmers' Views on Constraints of Crop Production in Dambos

4.6.1 Constraints to Dambo Utilization

1. Flooding of Dambos during the rain season limits growing of crops in them only in the dry season except for a few farmers who plant on high ridges, which they consider laborious to make.
2. Dambo soils are usually difficult to cultivate, particularly when wet or when too dry.
3. Hand hoes, axes and slashers are commonly used for land preparation at present.
4. Because of wet conditions, only certain adapted grass species prosper in Dambos. Such grasses form dense mats which are deep rooted up to 50 cm of the soil profile and thus make it difficult for farmers to cultivate the land.
5. Pests and diseases limit vegetable yields as farmers cannot easily control them due to lack of availability of chemicals in their areas, coupled with incapacity for them to afford these expensive pesticides when available. Sometimes chemicals become available very late when damage has already occurred.
6. Implements such as slashers, pangas, rakes, spades, hoes, cans and sprayers are not locally available for farmers to purchase in rural areas.
7. Credit institutions are not willing to give support to farmers on small vegetable gardens in Dambos as they favor upland fields with crops like maize. On the contrary farmers note that they find small Dambo gardens more lucrative than upland fields.
8. Unavailability of vegetable seeds and fertilizers (when required) hampers correct timing of planting. Sometimes cropping is completely abandoned. There is no flexibility to choose a correct cropping pattern.
9. Farmers have to deepen wells when water tables recede. In many cases a rope and bucket is used to draw water for watering vegetables. This is laborious and time consuming.
10. In fragile sandy soils, wells collapse easily.

11. Some Dambos are acidic in nature and thus require special knowledge on soil management or crop adaptability.
12. Excessive drainage may cause lowering of the water table.
13 Market for produce is not readily available in some cases and prices may vary greatly with time, sometimes disadvantaging the farmer.
14. Use of heavy machinery will dry the Dambo and destroy it permanently, especially where dam construction impedes downstream flow of water and change the water regimes.

4.6.2 Lack of Appropriate Technologies for Dambo Development

One of the primary constraints, given high priority by the farmers, is that of lifting water from shallow wells. The use of a rope and a bucket has been classified as a laborious and time consuming activity.

This study identified and helped to develop, in conjunction with the International Development Enterprises and FAO, a device known as a treadle pump for water lifting. This is a device which has reduced the time spent to irrigate gardens. The device has been demonstrated and many farmers have acquired the pumps. The pump is sustainable and appropriate as it does not require use of diesel, kerosene, petrol or electricity. Many farmers who have adopted this technology, have been able to increase the sizes of their gardens by two and a half fold from 0.10 ha to about 0.25 ha.

Another technology that has found a niche in Dambos, is the clay pot irrigation. This technology saves irrigation water and labour. It is appropriate for use in areas where water is scarce as is common in most parts of Africa. Chapters 5, 6 and 7 deal with the development, implementation and impact of these technologies.

4.7 Conclusions And Recommendations

1. Dambos have been recognized as resource areas in many countries and are exploited for various purposes such as eco-tourism, pastoralism and crop production. They have thus been called different names in order to distinguish them as special resources requiring special attention in technological research to contribute to national food security.
2. Dambos are not independent systems but are rather interconnected to the surrounding watershed and the hydrological cycle. Their sustainable utilization would thus largely depend on proper catchment management and water control in them.
3. For several decades farmers in Zambia, like those in floodplains of Egypt, Senegal, Niger and along the Zambezi have followed a risk spreading strategy to grow crops in Dambos. Crops planted at different times of the year and at different elevations or zones of a Dambo/floodplain eg. **Litongo** or **Sitapa** gardens ensure that some escape flooding and others escape drought. A variety of crops ripening at different times cope with differences in annual flooding patterns, ensuring a constant food supply and market opportunities.
4. Damming a Dambo outlet may cause permanent inundation in all potential crop production zones.
5. Most Dambos are rich in organic matter and being depressions surrounded by high ground, act as nutrient depositional areas. This makes them very fertile lands for crop cultivation although their nutrient pool may be negatively affected by soils becoming acid in nature.
6. Farmers have sustainably kept their Dambo lands fertile by supplementing with compost, livestock manure and to some lesser extent inorganic fertilizers. This practice has proven sustainable and no acidification problems have been reported so far.
6. Some farmers burn vegetation in Dambos during cultivation (especially on virgin land). In Dambos which are also used for grazing, this practice would promote regeneration of new herbaceous plants and grasses which are palatable for livestock to

graze.

7. On sour or acid Dambos which are deficient in basic nutrient elements, burning would further lead to loss of nitrogen taken up and stored in plant biomass such that if nutrients are not replaced, the Dambo would lose its fertility and become unproductive in the long-run. It is recommended to use manure after burning has taken place.
9. A major problem which exacerbate fertility loss in Dambos is erosion due to overgrazing which leads to loss of top soil and its nutrient reserves and lowers its soil moisture retention capacity. It is recommended not to overgraze on Dambo land and to keep appropriate livestock numbers for the Dambo carrying capacity. Unrestricted burning and grazing, it is believed, lead to gullying and drying up and this problem is likely to become more widespread and acute if there are increases in livestock numbers.
10. In as much as Dambos have been used stably and in a sustainable way by small-scale farmers, it is important that an environmentally friendly approach is adopted in their utilization.
11. Commercialized crop production which entail use of mechanized farm machinery like tractors to make drainage channels leading outside Dambos, should not be allowed as this would alter the water movement and its fate in which recycling would no longer be the case.
12. Creation of high ridges for free drainage in the root zone and formation of high flat beds without loss of water downstream or outside the Dambo, is a very sustainable way of utilizing Dambos.
13. Grazing of cattle in Dambos used also for crop production is reported to be the major cause of erosion and this should be discouraged at all costs.
14. Use of village headmen and chiefs in bringing about awareness among village communities has proven very useful particularly in Eastern province.

15 Deforestation in the catchment area is another big problem requiring control as this causes erosion and affects the water regime in Dambos since run-off rather than infiltration is promoted. Afforestation should be encouraged in Dambo fringes and their catchment areas in which planting of fuel woodlots would help re-afforestation.

CHAPTER 5

MODIFICATION AND INTRODUCTION OF TREADLE PUMPS AS TECHNOLOGY FOR OPTIMIZING LAND USE IN DAMBOS

5.1 Introduction

One of the strategies to rapidly increase food production in a drought prone country like Zambia is the introduction of technologies that would make it possible to produce food all year round by utilizing the available water resources. Many constraints abound in food production and these have been established and elucidated in this study. Dambos, which are scattered throughout the country and are accessible to a large number of Zambian farmers, are an option that this study has identified as a potential attribute that could increase food production, provided that production constraints are eliminated or mitigated. The major on the constraint is water and how this can be lifted for use in irrigated fields. Apart from mobilizing and utilizing the water, there is a need to conserve it since it is limited despite its abundance in the country. Paradoxical situations occur with water being poorly distributed and sometimes being over used.

The study has identified a very simple and inexpensive water lifting device (the treadle pump) as a low profile technological miracle, which without fanfare, has made millions of the world's poorest farmers from developing countries such as Bangladesh, India, Vietnam, Nepal and Cambodia double their incomes and step beyond bare subsistence. By using this device, farmers in these countries are able to harvest a second or third crop in the dry season and plant new varieties of vegetables and in some cases crops are being grown where nothing grew before.

5.2 What Is a Treadle Pump?

The treadle pump is an elegant foot operated human powered water lifting device which by using suction force, lifts water from rivers, swamps, reservoirs and shallow wells (hand dug) over a depth ranging from 0-8 meters to the ground surface where it is intended to be used by farmers for irrigation, livestock, domestic and other purposes.

To realize the potential use of this device into **"a dream come true"** for Zambia, this study embarked on the transfer of this technology and adapting it to the local prevailing conditions. Using the hydrological knowledge of some Zambian rivers and Dambo land, the study has established Dambos as a major niche for use of this technological device because of the existing shallow water tables throughout their places of occurrence.

These are similar conditions as those prevailing in the countries mentioned where this type of pump has been used successfully. The merit underlying the transfer of this technology lies in the fact that the treadle pump is made of locally available materials (i.e. scrap yard metal, wood and animal skin) which make it inexpensive and affordable by the small-scale poor farmer with a meagre financial resource base. Unlike the innumerable manual irrigation techniques that have been tried before and proved expensive, with lots of technical short-comings and out of reach of the poor farmer, the treadle pump is a farmers' friend whose return to capital is more than 100% even with the first crop.

The study has proven beyond doubt that designs of modern water lifting devices, which include motorized pumps, are expensive and sometimes inappropriate for Zambian conditions. The treadle pump is affordable and appropriate for the small-scale farmer (see Section 5.10). Some so called "appropriate low-cost technologies" involve costs as high as motorized devices and thus become unaffordable by the small-scale poor farmers whose large numbers would exert the kind of impact necessary to accelerate the rate of increase in agricultural food production to levels that would match or exceed the population growth rate currently prevailing. This is possible if and once appropriate and sustainable technologies are made available at low costs.

5.3 Treadle Pump Technology Development

The initial steps in transferring and developing the technology involved acquisition and testing of prototypes for the treadle pumps. The prototypes and blueprint designs were obtained from Bangladesh under a Special Programme for Food Security ran by FAO. This study identified that it was necessary to pilot the operation of the technology in the three Dambo study sites where hydrological research under this study had proven it was possible to grow crops provided water lifting and drainage were addressed.

Working with the FAO and IDE, an NGO spearheading the development of small-scale irrigation in Zambia, the author embarked on on-farm testing and later modifying the treadle pump prototypes according to field results/feedback from farmers to suit the existing conditions so that the pumps would be adopted by them. Piloting started in 1997 at three Dambo sites, i.e. Chipala Dambo, Noole Dambo and Mugabi Dambo in the Copperbelt, Southern and Eastern provinces of Zambia respectively.

Three types of treadle pumps were tested and modified according to farmers' suggestions in the field. The three prototypes included the tube well treadle pump, the river treadle pump and a pressure treadle pump. A tube well is referred to as a borehole in Zambia. Under Zambian hydrological conditions, boreholes have water tables that are too deep below the surface to use the tube well treadle pump, whose suction limit is 8 m below the ground surface. The pumps were piloted in the field for a period of one year. Although piloting continued in the following season, an appreciation level for the modifications made to the pumps had been reached to such a level that adoption started at a very rapid rate.

5.3.1 Operating Principles of Treadle Pumps

Treadle pumps are essentially manual pumps operated by human feet (Figure 14). Pumping is achieved by standing on the two treadles connected to pistons in the cylinder. By shifting the human body weight side to side the pistons in the pump cylinders are activated up and down to create suction pressure. The suction pressure creates a vacuum in the cylinders and by help of atmospheric pressure and force of gravity acting on the free water surface, water is forced to enter the pump cylinders through the inlet pipe connected to the junction box.

Except for the pressure pump, each upward movement of the pistons on the suction type pumps (original tubewell, modified and river pumps) lifts water by means of rubber cups fitted onto the pistons and discharges it through the spout. The pressure pump, though operating exactly on the same principles, on the other hand discharges water on the downward movement of the pistons by pressurizing it through the junction box to the outlet pipe connected to it.

Figure 14: The Treadle pump in Operation Activated By Human Feet.

The operation to lift water follows some ingenuity of connecting the pump to a water source by a pipe called **"inlet"** which is fitted with a non-return valve that allows water to enter this pipe one way and does not allow it to flow back to the water source.

Essentially the piston and the cylinder have a very close or tight fit so that when the piston is raised, it creates a vacuum in the cylinder and water is sucked into the pump. When the piston is pushed down (see Figure 15a), the water is pushed through a small valve in the piston to fill up the space above it. When the piston is raised again, it lifts this water until it pours over the rim of the cylinder and into an irrigation channel or tank. At the same time more water is drawn into the space below the piston. The downward stroke of the piston once again pushes water through the small valve into the space above the piston and the process is repeated (Figure 15a).

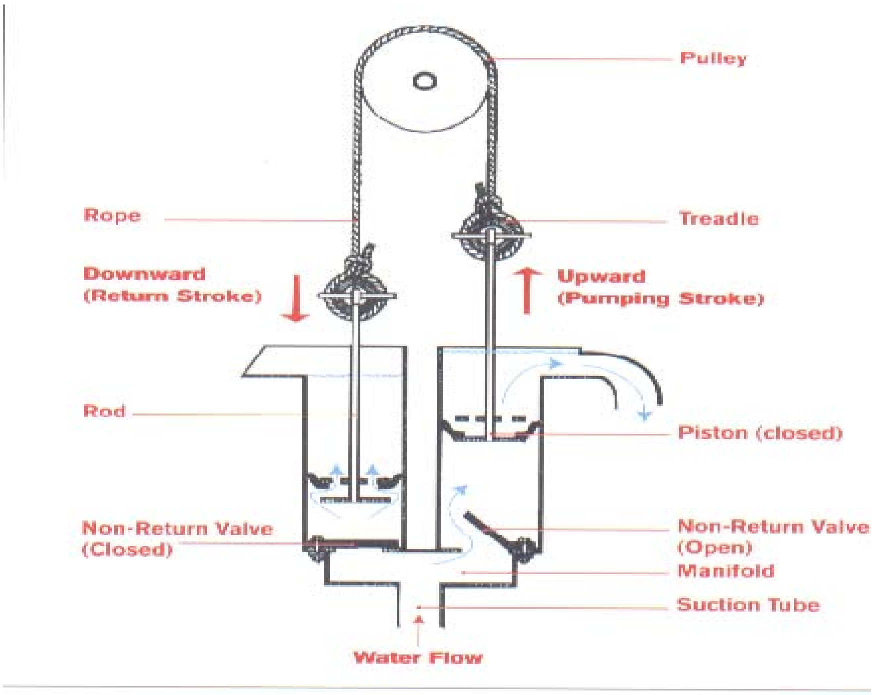


Figure 15a: **The treadle pump operating principles.**

5.3.2 *Structural and Operational Characteristics Of Different Prototype Modifications of Treadle Pumps Tested*

The treadle pump essentially consists of twin cylinders whose internal diameter is 89 mm except the pressure pump, which has an internal diameter of 100 mm. The optimal discharge at a suction lift of 7 m below ground surface is between 1.5 and 2.0 l/s. To operate the pump, internal parts such as foot valves, which allow water to flow in one way and stop it from flowing back to the source, the rubber/leather cups acting as seals with the cylinders and which lift water in a nearly continuous flow in these cylinders when fitted to the pistons that get connected to the treadles with a metal rod, are required to be assembled.

In case of the river and pressure pumps, a pulley wheel and rope connect the two treadles to the piston rods and enable the operator to work the treadles up and down in reciprocating movements. These are the complete mechanical parts of the pump. The pump discharges water on the upward stroke through a spout attached to the lips of the cylinders.

On the other hand, the pressure pump has an internal diameter of 100 mm and discharges between 2.0 l/s and 2.5 l/s at a suction lift of 0-4 m below ground surface. The internal parts consist of rubber flaps as foot valves and leather cups which perform the same functions as those described for the rubber valves and cups above. The leather cups fit water tight in the cylinders and as such pressurize water out of the cylinders through the discharge pipe on the downward stroke. The pressure with which the water is discharged depends on the operator's energy. As a result of the pressure created by the pressure pump, it can deliver water at elevations up to 7 m above ground level (or actually above pump level), whereas the tubewell, modified and river treadle pumps which are basically suction pumps can only lift water from the source and bring it to ground (or pump) level. The basic components which act as ancillary parts to these pumps are shown in Figure 15b whereas Table 18 gives a comparison of the characteristics of the different types of pumps tested in the field.

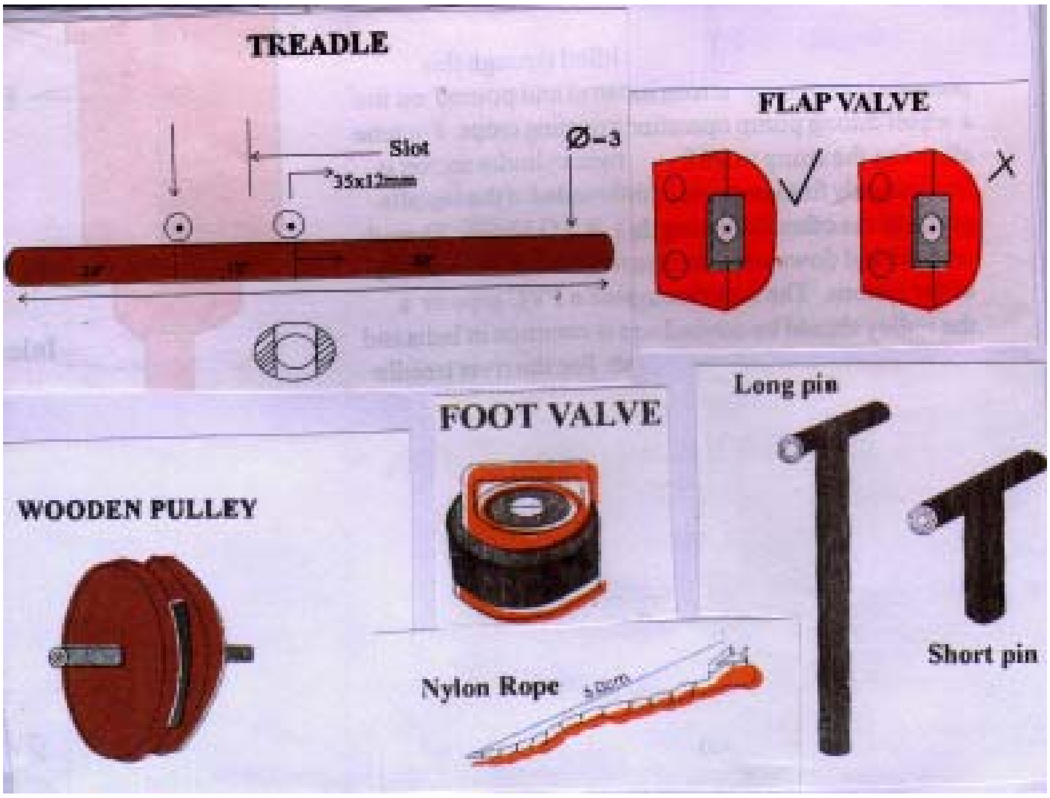


Figure 15b: Basic Ancillary Components Of The Treadle Pump.

Table 18: Characteristics of the prototype pumps and their components.

Characteristic	Tube well pump	Modified pump	River pump	Pressure pump
Suction lift(m)	0-8	0-8	0-8	0-4
Discaharge(l/s)	1.5-2.5	1.5-2.0	1.5-2.0	2.0-2.5
Delivery head(m)	0	0	0	7
Foot valve durability	5 years	5 years	5 years	3 years
Rubber cup durability	9-18 months	9-18 months	9-18 months	N/A
Leather cup durability	N/A	N/A	N/A	6-12 months
Pulley durability	N/A	N/A	1-3 years	1-3 years
Treadles durability	1 year	1 year	1 year	1-2 years
Pump head durability	5-7 years	5-7 years	5-7 years	5-7 years
Pulley string/rope durability	N/A	N/A	1-3 months	1-3 months

5.3.3 Super-structural Assembly

Three pump models as prototypes were tested and these looked different in terms of the structural appearance at final assembly and installation. Descriptions of each prototype tested, including the modified tube well treadle pump, are given in the following sub-sections.

5.3.3.1 Original prototype of the Tube Well Treadle Pump

The tube well pump comprises a pumphead with twin cylinders attached to a junction box where an adapter is fixed at the bottom to suit installation onto a shallow water borehole or a tube well. Alternatively a hosepipe is attached to this adapter and directed to a suitable surface water source. The pump has a rectangular shaped spout welded onto the twin cylinder head. This acts as a trough into which the pumped water is discharged under free-flow onto the ground in an irrigation channel or into any container when used for domestic purposes, as the case may be.

This pump requires a wooden or metallic stand post or a tree stump of 1-2 m height to anchor it on. The stand posts are installed into holes dug into the ground to a depth of 50 cm. Thus 0.5 m - 1.5 m of the stand post remains above ground. Disused rubber bands from either a vehicle or motorcycle/bicycle tube are used to tie the pump head.

Treadles, which have holes drilled in them, are fixed to the pistons and the stand posts, which are also drilled with holes, by connecting an iron rod through the stand posts, treadles and piston rod holes. The rod has punch holes through which wire pins are fixed to avoid the anchorage coming out unduly during operation. Figure 16 shows the complete assembly of this prototype.

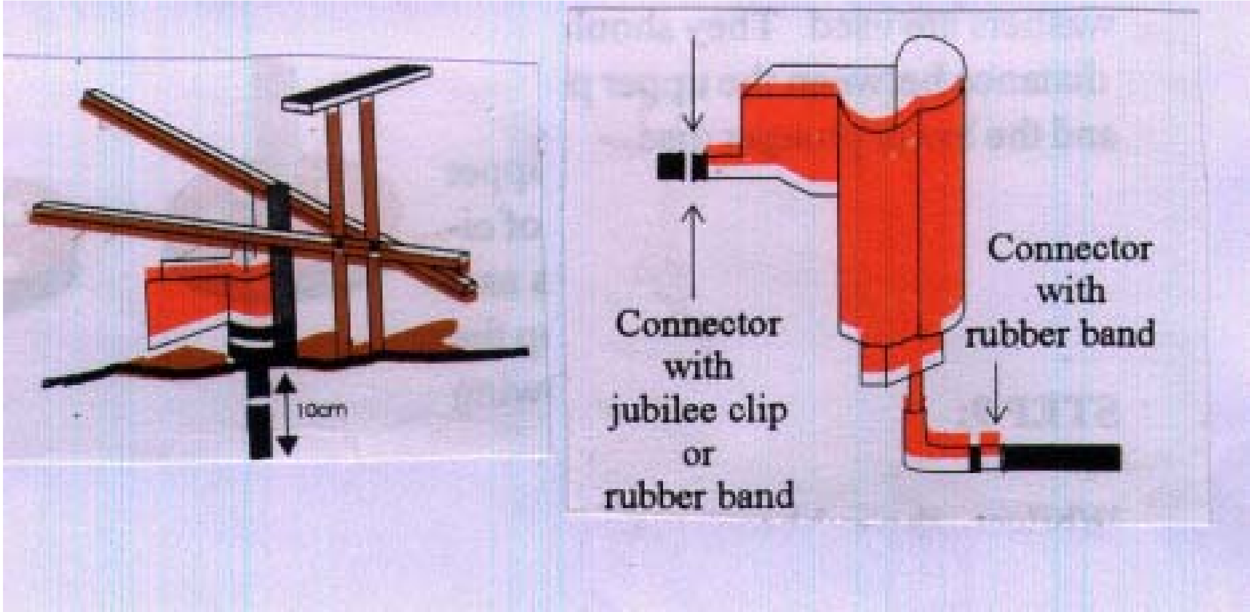


Figure 16: **The Well treadle pump assembly.**

5.3.3.2 Modified Well Treadle Pump

The modified pump is, as the name implies, a modification of the original tube well pump, which farmers found cumbersome and difficult to install in the field. It was not appreciated because one had to look for a stand post and dig holes in the ground for installing the stand posts onto which the pump was to be anchored. Farmers found that it was tedious to do this and it also took some time to do it properly. To make it a **"plug and play"** pump as farmers required of it, the pump was anchored with metallic stands **(legs)** in a tripod stand arrangement welded to the pump head. The pump is also provided with a fulcrum whose top is welded with a short metal rod (on the opposite side of the pistons) onto which the treadles would fit when connected to the pistons. In this way the pump legs are simply driven into the ground and a pipe connected to the suction side composed of a short pipe connected to the junction box and then it is ready to operate. In this way the pump has been made easy to install within a very short time and the assembly becomes firmer compared to when the pump head is anchored by use of rubber bands. The spout has also been fitted with a 50 mm round pipe to make it suitable for fitting a hosepipe when required. This can be done because the metallic legs elevates the pump head to a metre height, from which water can easily flow by gravity in a hose pipe to the ground surface in the field (Figure 17).

Figure 17: **The modified well treadle pump superstructure.**

Because of the ease of installation and operation of this modified pump, FAO requested modification of all the 350 original well treadle pumps which were originally brought in for piloting, but were not preferred by farmers. After modifications, all the modified pumps became appealing and were bought by farmers. This model has become so popular the original well treadle pump has been phased out due to farmer preference for the modified version. Users can, however, request manufacturing of the original well treadle pump if needed or preferred under varying circumstances.

5.3.3.3 The River Treadle Pump

The river treadle pump has exactly the same arrangement of twin cylinders with a rectangular shaped spout attached to them as the tube well pump. The major differences are that the junction box is connected with a 40 mm inlet manifold pipe to which a suction hose pipe is attached and connected to a water source.

The junction box has two metallic bolts welded on both sides, where wooden platform pieces are fixed and tightened with nuts. This makes the pump head stand in a vertical position to the ground. Two metallic rods with grooved heads are welded to where the twin cylinders meet. These grooved rods stand vertically above the cylinders and enable the installation of a wooden pulley, which has a metal rod passing through the centre hole. When the two ends of the rod are in the grooves, the pulley is located exacly in the centre where the twin cylinders meet. Treadles are attached to the cylinders by means of a rope which passes over the pulley and connects the two pistons in the cylinders. This assembly makes the pump stable, as the wooden platform can be shallowly placed into the ground to make it firm during operation. Figure 18 shows how the river pump is installed in the field.

Figure 18: **The river pump superstructure after installation.**

5.3.3.4 The Pressure Treadle Pump

The pressure pump superstructure is one that can be described as robust and the easiest to install since one only requires to take the pump close to the water source and place it on a horizontal surface. With a pipe connected to the inlet manifold and taken to the water source, the pump is ready for operation. Unlike the three models described above, the entire assembly is well connected together without any need to install the superstructure in any special way.

The twin cylinders and an adjustable metal frame onto which the pulley and a T-bar, which the operator uses to hold his hands on, are welded together. The junction box which has provision for inspecting the internal flap valves has a base with a flanger fitted with a rubber gasket around. The junction box and the base are bolted together by using nuts. The base frame is welded together with the bottom base of the junction box. Attached to the base frame are the inlet and outlet (discharge) pipes. The inlet pipe is longer than the discharge pipe so that it provides a fulcrum or pivot centre attached to it in a special way for the treadles to get connected with this point and the pistons directly vertically into the cylinders. Figure 19 shows the pressure pump superstructure.

Figure 19: The pressure pump superstructural assembly.

5.4 Suitability of Treadle Pumps for Use in Dambos

Despite the limitation of suction lift, particularly in areas with deep water tables, these pumps can easily be operated in Dambos as water tables are normally shallow, i.e. within a depth of 0-3 m even during extreme dry periods as found in this study (see Chapter 3).

The ***well treadle pump*** is highly suitable for use on hand dug protected shallow wells usually used for drawing domestic water. In this case the well is capped with a concrete cover to protect dirt from falling into it. Thus, sanitation is assured as the well treadle pump is installed onto the opening of the cover to also seal the well. Instead of using a windlass, a rope and a bucket tied to it, users just operate the pump and fill their containers with water in a very short time (see Figure 20). Some farmers are using this pump installed onto the well located in the middle of garden to pump water into a drum whose bottom is fitted with two pipe outlets onto which hosepipes are connected to reticulate water to vegetable garden plots. The pipes are shifted as required after a plot is adequately irrigated. All the operator does is to continue filling up the drum when water depletes. When the drum is full, the pressure head is good enough to deliver water over some distance up to 50m within the garden. As the water depletes so does the pressure head reduce. This makes irrigation very easy as compared to drawing water from streams, filling up drums placed in a garden or indeed drawing the water from the wells using ropes and buckets and walking to vegetable plots to irrigate. The engineus use of this pump has reduced the labour for irrigation by women who mostly do the watering in gardens.

Using the pump even reduces the number of wells that needs to be dug. In Dambos, a single garden may have one to three hand dug shallow wells located strategically so that different parts are irrigated within short distances from the water source, using watering cans. The advent of treadle pumps has made this job easy since only a single well fitted with a well treadle pump is required per garden.

Similar situations also occur elsewhere. On the central plateau of Burkina Faso it was seen that women would use a rope and a bucket to draw water from a well situated strategically in the middle of the garden and tip it close to the well into furrows sloping away from it to irrigate vegetables (Laker, 2000; personal communication). The well treadle pump is certainly a more user-friendly alternative to this laborious technique.

Figure 20: A tube well treadle pump installed onto a capped well for easy drawing of water.

The ***river treadle pump*** is used for irrigating gardens that are on relatively flat ground with gradual slopes along small canals or streams. From the canal or stream water is delivered into furrows, the gradual slope allowing water to flow easily in them. Apart from furrow irrigation, micro-basins which may be rectangular or square in shape and bunded with earth on all four sides are made by farmers to allow them irrigate the crop planted in them. It becomes easy to flood these basins with water and allow it to infiltrate into the soil. No skill for water control is required as water cannot flow out of the basins. For the river pump to effectively irrigate such gardens, it is installed on a relatively higher ground than the rest of the garden in order to let the water flow by gravity in an irrigation channel that leads the water into furrows or basins (see Figure 21). Some farmers use short flexible hose pipes, or pvc pipes fixed to an adaptor that is welded onto the pump to direct water to these infield structures. The pump is designed to pump water from surface sources such as rivers, swamps and dams. Although it can pump water from a shallow well or borehole as well, the way the inlet pipe enters the well/borehole from the pump is such that it bends. During pump operation, the bending point easily collapses and causes problems in operating the pump. It becomes hard to operate with water flow through the point where the pipe has collapsed being restricted.

Elsewhere where river treadle pumps may be very useful include the following: Firstly, in parts of South Africa the indigenous small-scale farmers have developed very efficient short furrow irrigation systems (De Lange, 1994). The main limitation of these systems presently is inefficient water delivery to the irrigated fields. The river pump could help to alleviate this limitation. Secondly, in Madagascar a case was observed where irrigation of a whole hectare potato field was done manually from a small canal diverted from a river. Men fill containers by scooping water from the canal and carrying the buckets or transporting small containers on wheelbarrows to different spots along the side of the field, where it is emptied into 200 litre drums from which the women draw it, using watering cans to irrigate the field (Laker, 2000; personal communication). The river treadle pump is certainly much better alternative to these laborious techniques. This specific situation would have been ideal for such pump: the canal is a little higher than the field and not too far from it. The field is flat, with a gentle slope in one direction. Since furrows are automatically formed during the ridging of the potatoes, combining the pump with a short furrow system could have been ideal.

Figure 21: Micro-basin And Furrow Irrigation Using a River pump.

The ***pressure pump*** is suitable for irrigating undulating ground because it has an ability to pressurize water from a source located on lower ground than the garden. Such situations occur where a farmer has to pump water from a river with steep banks and irrigate a crop that is higher up on an undulating surface. In this case the pump is located close to the water source, giving it an advantage of low suction lift, but allowing it to pressurize the water over the steep bank and indeed one can apply it in a fine spray like rainfall or direct the flow on the soil surface and flood the soil. Pressure pumps are also used to pressurize water to sprinklers, drippers and elevated head tanks.

On-farm field tests by farmers revealed that ***all the devices*** provided a better alternative for water application and distribution to their crop than using a rope and a bucket or scooping methods as shown in Figure 10 which they described as tedious and labour intensive to use.

Field tests revealed the following observations for the different pumps:

- The pressure pump appeared to operate smoothly and optimally at suction lifts of not more than 2 m as opposed to the range of 0-4 m described in Table 18. Moreover, the pump becomes hard to operate at a suction head of more than 4 m and in most cases fails between 7 and 8 m.
- The pressure pump exhibited an ability to deliver water up to a height of 7 m from the ground surface whilst the suction river and modified well pumps have no delivery head.
- The pressure pump, where required, would offer the advantage of delivering water from a water source to the field level over a height of the river bank or indeed can be used to take water into an elevated tank from which it can be gravitated to the field or be used for domestic purposes.
- The river pump, tube well pump and its modified version are easier to operate than the pressure pump at all suction ranges up to 8 m. Both women and children from the age of four years could easily operate the three pump types.
- The river, modified and pressure pumps are easier to install **(plug and play)** than the tube well pump whose installation farmers described as cumbersome and time consuming (see section 5.3.3.1).
- The tube well pump, which originally was adapted to boreholes, did not find much application in the field unless modified to suit abstraction of water by installing it onto a stand post in the field away from the well capping directly above the water source. Adapting it to quick installation as is obtained with its modified version was the farmers' desire in the field.
- Despite the ease of operation of the river pump, farmers called for an adaptation which would enable plugging in of a pipe at the discharge spout in order to allow reticulation of water through surface furrows as well as a hosepipe conduit.
- The lifespan of the foot valve and rubber cups greatly depend on the type of water being pumped.

- If muddy and sandy water is used, these components will wear out within a few weeks.
- It is important that the water sources are deep enough for the water not to run out. The wells should be lined with concrete rings so that water would be clean and recharge improved.

- It has been proven that the pump head, which is metallic, can last for as long as five to seven years when looked after well. In Zambia, water is often of good quality and this prolongs the lifespan of the pump to as much as ten (10) years with good maintenance.
- After four years of use in the field, it has been observed that the metallic components of the pumps
- Are the most difficult to wear out. However, it was found that most replacements had been done to the rubber cups and valves. About 10% of the pulleys had also been replaced on the 2500 pumps purchased over the three years.

5.5 Sustainability

To make the technology sustainable the study undertook to make available a manufacturing base, which would supply the pumps locally once demand was created as a result of piloting the technology. In Zambia there is a manufacturing potential from both big and small-scale manufacturers. A number of retired and retrenched artisans from the manufacturing industries have set up their own workshops for metal fabrication and foundry works.

In order to create competition, both small and big manufacturers were trained in the manufacturing of the treadle pumps. Some carpentry outlets were also trained in producing the wooden components, i.e. the pulleys, treadles and base stands for the river pump. These activities created employment at the manufacturing/assembly line. Six small-scale manufacturers who are geographically separated by distances and located in different provinces were trained in manufacturing the pump. Besides these, three big manufacturers were also trained. The big ones are characterized by a higher capacity to produce more pumps per day than the small ones. Often the big ones would produce about forty pumps per day as compared to six or ten per day for the small ones.

In Lusaka the small-scale manufacturers include Kasisi Agricultural Training Centre (KATC), DEN-MWA Engineering, Milo Investment and Chokwadi Investments. In Eastern and Copperbelt provinces they include Katopola Agricultural Engineering Services (KAESE) and DAVACA respectively. The big manufacturers are all Lusaka based and they include Knight Engineering, SARO Agricultural Engineering and SAMS (Small Agricultural Machines Services).

All these selected manufacturers were trained in manufacturing the pump on a demand-driven approach after they requested participation in disseminating the technology through manufacturing. This was manifest after they saw the demand for this humble device by farmers apparently increasing. To date there are nine treadle pump manufacturers.

All manufactured pumps are quality controlled by IDE marketing and quality control officers to ensure there are very few or no faults when in use in the field. A one-year warranty is given for any quality controlled pumps purchased by a farmer. It is the duty of manufacturers to ensure that high quality pumps are produced to minimize the frequency of breakdowns in the field, because these would erode consumers' confidence in the technology. The technology is sustainably available for as long as demand exists on a sustainable level.

5.6 Maintenance and Repair

The treadle pump pump has been designed and manufactured in such a way that it is easy to maintain and repair by an average user at village level. While the pump can last up to seven years, the internal movable parts (rubber cups) can last between 9-18 months, depending on the use and source of water. It has been established that sandy and muddy water will wear out the rubber cups in just few weeks time.

In order to increase the lifespan of the internal moveable parts, it is recommended to use a strainer at the intake in order to prevent debris coming into the pump. The foot valve can last as long as the pump itself, except the rubber flap which allows water one way into the pump by opening and closing. However, this moveable part can easily be replaced by making one from disused bicycle or motor vehicle tube.

The nylon rope, which moves over the pulley, may also break easily but animal skin hides, old bicycle chain and old fan belts easily replace this.

The wooden treadles can be made from any wood found in the village, provided a carpenter drills holes at correct intervals. When mukwa wood is used and treadles operated properly, the lifespan, which is normally one year, can extend to three years.

When leather cups are used, it is advisable to pre-soak them in water to allow them expand and create enough suction force when priming the pump. This applies to the pressure pump. Leather cups shrink when dry and this makes priming difficult until it has wetted enough.

When the pumps are not in use, they should be stored in a cool storage place and protected against corrosion by greasing the internal matallic parts of the cylinder.

Rubber cups, leather cups and foot valves should be kept away from rats, as they would damage them.

5.7 Training of Distributors and Users (Farmers)

The technology cannot be sustainable if those who distribute and use it in the field do not appreciate its use. Training in retailer/farmer relations, record keeping on sales, after sale service and quality control has been given to twenty-eight distributors throughout the country. They have also been trained in the installation, operation, maintenance and repair of the treadle pump. This ensures that they too explain the use of the pump to farmers (users) at the time of purchasing at retail outlets. Ministry of Agriculture Food and Fisheries (MAFF) technicians at camp level and key staff of collaborating agencies in the dissemination of the technology have also been given the same training. MAFF staff in turn train their camp officers who are in touch with farmers on a day to day basis and give the same training to them. This makes the supply chain sustainable.

5.8 Distribution Network of the Treadle Pump

A distribution network consisting of manufacturers, wholesalers, retailers, NGO/private partners and farmers as consumers (users) of the technology has been established. A network of twenty-eight retailers and forty active collaborating partners, including government departments that deal with the distribution and sale of treadle pumps, has been activated throughout the country. This replication of a marketing or dissemination chain is called "Rural mass-marketing". To accelerate and respond to the demand of the pumps, IDE makes available the technology to the retailers on consignment basis and they receive commission on each pump sold.

Due to an accelerated demand of the technology, retailers are slowly linking themselves straight to manufacturers for the supply of pumps. This is a positive aspect of sustainability since IDE as a supplier will not always be there.

5.9 Technology Dissemination and Promotion

Recognizing that technologies do not market themselves, the study embarked on carrying out promotional activities with IDE in the field. These included physical pump demonstrations at farmers' fields where hydrological conditions for suitable water sources exist. *In situ* demonstrations were also carried out at market places where farmers sell their produce and at

IDE field offices. Besides, live theatre troupes have been used to write a play that would have entertainment value while it stimulated pump sales. These demonstrations took place in Eastern, Lusaka, Central and Southern provinces.

Demonstration plots using treadle pumps were also established at strategic places where the pump visibility would offer a chance for a prospective treadle pump purchaser to try the pump at his own time. Pamphlets, leaflets and brochures explaining the use of the pump and where it can be bought from are distributed to clients during organized field days and agricultural shows/exhibitions. Other strategies to popularize the technology have included printing of calendars and T-shirts that depict the use and benefits of the technology. Other means include advertising the technology at retail outlets, in print media (Newspapers) and on radio programmes and interviews.

5.10 Pricing Structure of the Pump

The river and modified well pumps both cost ZK140,000 (US$40) from small-scale and ZK175,000 (US$50) from big manufacturers. The pressure pump is more expensive at ZK294,000 (US$84) and is produced by SARO Agricultural Engineering. Prices vary primarily due to higher overhead costs of big manufacturers compared with the small ones. On the whole, farmers feel these prices are affordable as they are within the range suggested by them during the Participatory Rural Appraisal (PRA). The farmers expressed their feelings as to what they could offer to buy the technology after demonstrations. Some felt they could give a cow or ten goats in exchange for the pump. These prices are pan-territorial (uniform regardless of the geographical distance from the point of manufacturing to the retail point) but it is increasingly becoming important for arbitrage to command. This means that unless transport costs continue to be subsidized by IDE as supplier to retailers, prices will increase away from the point of manufacturing. One counter-measure that can redress this situation is to establish manufacturers in areas where demand is rapidly increasing.

5.11 Brand Naming of the Technology

After modifications and successful piloting in the field, more and more pumps have been sold to potential users. The farmers have praised the treadle pump in many ways with respect to its uses and the role it has played in generating income and achieving household food security. As a result of this, the farmers have renamed the treadle pump as a **"Chova"** pump. **"Chova"** is an indigenous vernacular word which is understood countrywide and around the region in Malawi, Tanzania and Zimbabwe to mean the following:

(a) To boost
(b) To pedal

By connotation of the word Chova pump, the farmer quickly understands that this pump can boost or increase farmers' income and that it is operated by pedalling using feet. The Chova pump has recently gained popularity without much effort to advertise it. This is due to the spread of the message by users who have since purchased the pump. This pump has not only transformed the small-scale farmers' farming systems but also improved their livelihoods by generating income from growing crops throughout the year as opposed to once in an annual cycle. **"Chova pump"** has become a household name in Zambia because of the positive impact it has had on the resource poor small-scale farmers.

The impact of the pump has resulted in a demand for the technology in neighbouring Angola, Malawi, Tanzania and Zimbabwe also. This has compelled IDE to consider starting up a programme in Angola and Tanzania where Dambos (called **"Mbungas"**in Tanzania) will be utilized for food production. The Chova pump is certainly the poor farmers' friend as it transforms a poor hard working farmer's status to a level where he/she can afford basic essentials of life and have surplus for household food security.

5.12 Adoption Rates

Figure 22 shows adoption rates of the technology from inception of the study in pilot areas from December 1996 to December 1999 according to type of pump.

The large number of pumps installed in the first year (1997) are primarily demonstration pumps which were given to farmers on a loan basis to be paid for after making profit from their use to produce crops. Three hundred and fifty such pumps were installed in various Dambo sites where other farmers without pumps could see them. In some cases farmer groups owned the pumps in order to irrigate crops and generate enough income to buy more for each group member. The figure shows that many more tube well pumps were put in the field during this promotion/demonstration phase than the other models. However, farmers did not appreciate them and this resulted in their being modified by the end of 1997.

This marketing effort resulted in twenty tube well pumps, fifty river pumps and fifty pressure pumps respectively being bought by individual farmers who appreciated the technology. The tube well pump was phased out as is indicative in the figure wherein only the river, modified and pressure pumps received continued demonstrations in the field and subsequent purchases show that these models are quite competitive. The river pump received more purchases than the modified and pressure pumps. This is particularly because it is user friendly in terms of easy of installation and operation. The river pump is also adaptable to a wide range of field conditions and is easy to carry back to the homestead after use to avoid theft in the field.

Coupled with *in situ* field demonstrations, the Chova pump technology began to catch on in many districts and provinces with farmers buying the pump on a cash basis. With more pumps being bought by individual farmers each year, the technology has spread to all provinces of Zambia with many other individual organizations involved in agriculture joining the dissemination effort.

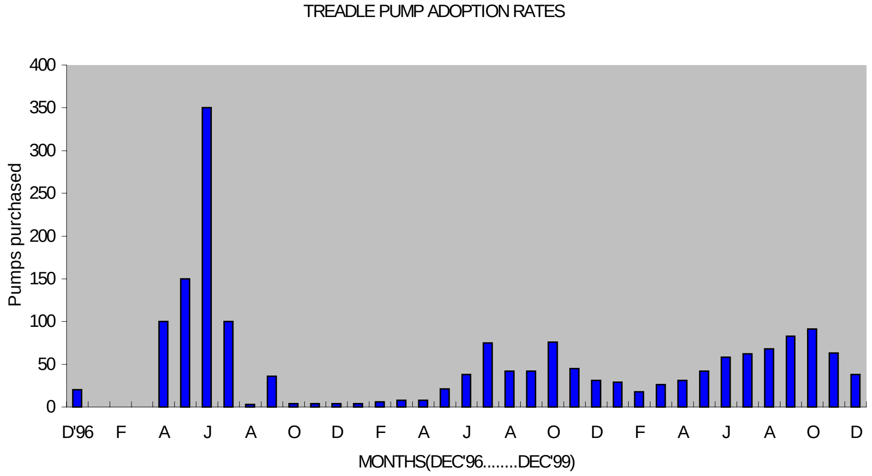


Figure 22: **Adoption rates of treadle pump technology.**

Figure 22 indicates a cyclic adoption with characteristic climaxes during the months of April to October and anticlimaxes during November to March for the years 1997, 1998 and 1999. The fact that more pumps are bought between April and October each year, is attributed to the coincidence with the dry season when irrigation becomes important and water lifting becomes critical for growing crops. The highest monthly sales were during October, which recorded eighty-six pumps bought, with more purchases coming from collaborating institutions. This may seem strange because October is the beginning of the rain season. It has relatively low rainfall, however, and the highest temperatures of the year. The latter leads to extremely high evaporative demands, giving October the biggest moisture deficit of the year. This month is often called the "death month" in Zambia (Kwaw-Mensah, 1996). This is illustrated in Figure 2. Sales of Dambo produce on local markets can fill the “hunger gap” (Figure 23).

Figure 23: **Sale of Dambo vegetables during hunger periods in Zambia (photograph: Kwaw-Mensah, 19996).**

The rain season is characterized by few pump purchases because farmers depend on rainwater for growing crops during this time of the year. It is anticipated that with irrigation using the Chova pump becoming popular and farmers appreciating the cost-benefit comparative advantage of the pump, purchases are expected to smoothen out throughout the year. This is expected along with the changing socio-cultural and farming system changes taking place. The Chova pump is a simple, inexpensive tool whose benefits can be achieved without the necessity of investing in dams, canals or other vast and environmentally unfriendly mega-structures.

5.13 Conclusions and Recommendations

1. The development of the treadle pump followed a participatory approach in which farmers
   were involved to field test the technology and give feedback for any shortcomings or appreciation on the performance. This had two unique advantages: Firstly the technology is adapted to field conditions and according to the operator's appreciation based on real life experiences and secondly the resulting models are easily adopted as they most likely meet farmers' requirements.
2. Any appropriate technology, no matter how good, cannot sell itself. What is required, is to market it and make it available by activating a local manufacturing capacity. This study has achieved this through promotions and training of small-scale producers of the pump.
3. The understanding of the Dambo hydrology and the existence of Dambos and surface water from rivers in Zambia has provided a potential niche for the technology. This would provide a source of livelihood option if adopted by over 800,000 small-scale farmers in the country.
4. The current adoption rate of 2,500 pumps in less than three years is a manifestation of an appropriate technology, which small-scale farmers can use to revolutionalize their lives and defeat the current droughts. It is imperative that with a single pump being used by a household of six members, there are about 15,000 beneficiaries of this technology.
5. Labour savings on irrigation by some 75% has resulted in an increase of vegetable garden sizes from a meagre 0.1 ha to between 0.25 ha and 0.50 ha.
6. The treadle pump is a gender friendly technological package which women easily operate.
7. The technology does not use fuel (kerosene, petrol or diesel) but depends on the operator's energy. The ease of operation allows an average farmer working with it for eight hours per day, being able to irrigate up to 1ha at that rate.
8. The treadle pump has been brand named as **"Chova pump"** by the Zambian small-scale farmer in appreciation of its performance and contribution to household food security.

CHAPTER 6

IMPACTS OF TREADLE PUMP INTRODUCTION ON DAMBO FARMING SYSTEMS AND SOCIO-ECONOMIC ASPECTS

6.1 Introduction

A Participatory Rural Appraisal (PRA) carried out after one year of piloting the treadle pump technology, reveals some positive impacting information regarding the intervention in the selected sites. This chapter discusses the impact of the treadle pump in Dambos and its relevance to household food security. Information is documented as revealed by about sixty small holder farmers belonging to Water Users Association groups that were initiated by this study. The study sites include Chalata, Fikolwa, Musofu, Siachitema, Noole, Mugabi and Nkumbi Dambos in Zambia. A post harvest data capturing of the 1997/98 irrigation season was done. Eight key farmers comprehensively provided income data from Dambo gardens and are thus highlighted in this chapter.

6.2 Crops Grown in the Pilot Sites

It was found that before the introduction of treadle pump technology, farmers grew vegetables with a primary aim of providing for the livelihood of their households and only sold something if there was surplus or when some urgent need for cash arose. In this way, only a limited range of vegetables was grown. All farmers in the pilot sites mostly planted vegetables like rape, cabbage and tomatoes. With the advent of the treadle pump, a diversification of vegetable varieties is noticeable. For instance, Figure 24 reveals that a wide range of crops are grown particularly in the cool dry season when diseases and pests are not common. Farmers attribute this diversity of crops to the use of treadle pumps since they are able to plant large areas of their gardens given the time gained on irrigating. Farmers at Fikolwa, Musofu, Kanchele and Chalata grow a range of 8, 13, 12 and 6 different types of vegetables respectively during the dry season and 5, 8, 4 and 3 vegetable types during the wet season. The very big difference at Kanchele Dambo is particularly noticeable. The reduction in the range of vegetable types grown during the rain season, is due to the prevalence of pests and diseases for some crops like tomatoes and cabbage and frequent flooding in the Dambo.

At Siachitema and Nkumbi Dambos as many types of vegetables as in the dry season are grown in the rain season. The two Dambos are extremes in terms of number of types of vegetables grown, with a high number (10) being grown at Siachitema and a very small number (4) at Nkumbi. It was found that the farmers at these two sites had recognized that the time when it is most difficult to grow vegetables (the rain season) coincides with high market prices for vegetables because of a scarcity of vegetables at this time.

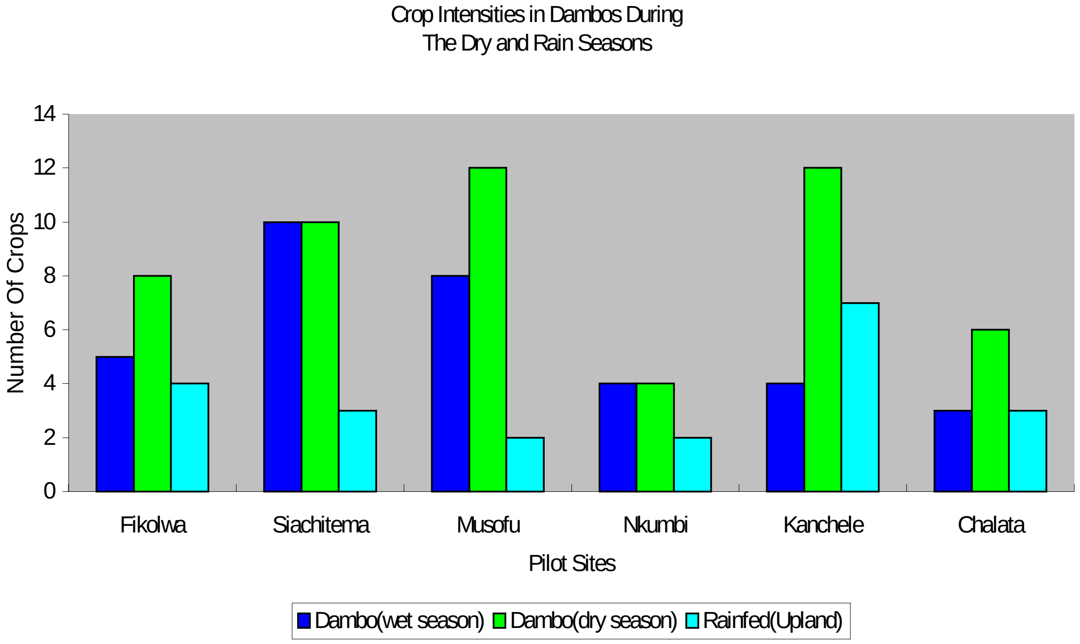


Figure 24: **Crop diversities in Dambo sites during the dry and wet seasons/rainfed cropping.**

The scarcity is caused by high prevalence of diseases and/or flooding, which results in low yields unless counter measures are taken. In order to coincide with high market prices, these farmers force production by investing in pesticides and other agro-chemicals for the control of pests and diseases and also to grow these crops on high ridges or flat beds to create a normal rootzone which is free from flooding hazard. Khuvutlu & Laker (1993) at Middle-Letaba irrigation scheme for small-scale farmers in South Africa also found similar patterns. They observed two reasons for off-season production of crops:

1. The farmers grew Okra in winter although it yielded less in winter than in summer. Because of food scarcity in winter, Okra prices in winter are so much higher that the profit per hectare is higher than in summer.
2. The farmers adopted a system of spreading work throughout the year so that they have work for their laborours the whole time.

6.2.1 Crop Diversification due to Treadle Pump use

Due to use of the treadle pump and ensuing increase in sizes of gardens (see Section 5.13), farmers have diversified their cropping (Table 19). Exposure to many types of crops and the availability of a market for produce has enhanced growing of different crops. Information from this table shows evidence of a higher range of crops grown by farmers in the study area after the introduction of the treadle pump technology as opposed to the period before this intervention. Farmers indicated that very limited land can be cultivated to vegetables if watering is done by hand using watering cans. This is one factor that caused low diversification of crops before the introduction of treadle pumps.

Before the introduction of treadle pumps the interviewed farmers grew crops that were limited to maize, cabbage, rape and tomatoes (Table 19). Production was also limited to household consumption and very little was sold at local markets. (See also Kwaw-

Mensah, 1996). With the advent of the treadle pumps, crop diversification is evident with the inclusion of irish potatoes, watermelons and sugarcane to the previous cropping patterns. Larger volumes of crops produced also became characteristic as farmers could now expand their gardens. This opened up avenues for outside markets in addition to the local ones.

6.3 Synergy between Rainfed Cropping and Dambo Vegetable Growing

At all sites farmers grew some upland crops during the rain season. This was most pronounced at Kanchele where cotton as a cash crop, maize as a staple, sorghum as a drought tolerant crop and groundnuts were still held in high esteem. At this Dambo upland rainfed cropping becomes more prominent during the rain season than Dambo cropping. The main reason for this is that at Kanchele most of the Dambo zones get too flooded, making it difficult to grow any crop during the rain season. There are two reasons for this: Firstly, water tables at Kanchele Dambo are usually high throughout the year on account of an earth dam upstream from the Dambo gardens. This has implications on the Dambo areas getting recharged from this severely leaking dam. A cut-off drain below the dam, to divert the water leaking from it, could solve the problem. It follows therefore that the first rains immediately begin to inundate the seepage/central zones of the Dambo because of additional supply of water. Secondly, the soils in the Dambo area at Kanchele are poorly drained because of their heavy clay texture.

On the other hand upland fields have well-drained soils which can support a wide range of crops, including rainfed vegetable crops. This explains why there is concentration on upland rainfed cropping during the rain season. Farmers are innovative by having a mix of easily storable and drought resistant crops like groundnuts and sorghum respectively.

This strategy will ensure that any possibility of drought occurrence can be escaped by the drought tolerant crops and surplus storable crops produced during good seasons can be stored for use after bad seasons without perishing. A cash crop like cotton will counter any shortfall of the staple maize since such cash can be used to buy the staple maize during times of scarcity. Another perculiar phenomenon which coincides with a reduction in lowland vegetable cropping is a conspicuous lack of a market at this time of the year because the Mapatizya amethyst mine is normally closed at this time of the year. The miners at Mapatizya are the biggest consumers of vegetables from Kanchele. Thus the availability of a market has an influence on the cropping pattern at this location. Compounding this is the abscence of a local market because everyone is able to grow his/her own vegetables in upland fields for household consumption.

At Musofu, Fikolwa and Nkumbi tobacco, cotton and maize were the main upland rainfed crops. Land preparation and planting of these crops at the onset of the rains in November affected Dambo activities significantly whereas weeding did so only very little. During land preparation and planting of upland crops, the whole morning and part of the afternoon is spent in upland fields. Only two hours per day are dedicated to Dambo gardens. However, all farmers interviewed submit to the fact that there is more income generation from Dambo gardens than from upland fields. Thus there is a clear shift of farmers to specialize in vegetable growing in Dambo gardens all year round and earn income that can purchase the staple maize or household food requirements. This is supported by the unreliability of the rainfall pattern in these areas. Droughts often cause crop failures in rainfed upland cropping, particularly with the staple maize.

Taking into account the crop diversity due to dry and wet season Dambo cultivation and wet season upland cultivation of maize, tobacco, cotton and groundnuts in the pilot areas, it was found that the diversity is greatest at Siachitema, followed by Musofu, Fikolwa and others (Figure 25). Farmers at Musofu, Fikolwa and Nkumbi are motivated to grow many crop types throughout the year because of access to big markets. Their buyers come from as far as the Copperbelt and others from within the district, particularly the secondary school and the hospital. Women buyers from the Copperbelt have organized a regular transporter called DODOMA to take them to these gardens twice a week to buy produce which they resell at Masala market in Ndola on the Copperbelt. In this way, the market is predictable. Nkumbi and Msofu are easily accessible as they are very close to a tarmac road. Fikolwa, however, because of soil acidity requires acid tolerant vegetables. This is the reason why only 5% utilization of the Dambo is exhibited in this Dambo (see Section 6.9).

Siachitema farmers with the highest consistent year-round diversity, market their produce at Choma, a nearby town, which is very near the railroad line, which opens up avenues for buyers from Livingstone, a tourist town.

Table 19: Crop Diversification Since Adopting Small-scale Irrigation using treadle pumps.

Farmer	**Dambo**	**Year started**	**Crops grown**	**Method of Irrigation**	**Treadle pump Involvement**	**Crops grown**	**Method of irrigation**
Charles Chiswala	Fikolwa	**1981**	Rape,maize	watering can	**1997**	rape, cabbage, tomato, sugarcane, water melon	Treadle pump
Morgan Bwale	Chalata	**1987**	Rape,tomato	watering can	**1996**	tomato, cabbage, maize, rape	Treadle pump
Cholobola Ngosa	Musofu	**1977**	rape,tomato, maize	seepage capillary rise, watering can	**1996**	rape, tomato, cabbage, peas, impwa, carrot, onion, cauliflower, green pepper, eggplant, water melon, irish potato	Treadle pump
Neli Banda	Nkumbi	**1990**	Cabbage,rape, cauliflower	watering can	**1996/7**	rape, cabbage, cauliflower,tomato	Treadle pump
Robert Simawawa	Siachitema	**1987**	Maize,tomato	watering can	**1996**	rape, tomato, cabbage, impwa, carrot, onion, cauliflower, green pepper, eggplant, paprika, watermelons, irish potato, cassava, gourd, maize	Treadle pump

At Chalata farmers do well, despite having a small range of crops. Tomatoes are grown all year round as main crop due to good control of pests and diseases. A farmer at Chalata has in fact a higher net income than most farmers interviewed in the pilot sites due to correct timing of the market situation and use of a treadle pump for irrigation. This farmer grows tomatoes throughout the year by staggering the planting of nurseries. In this way, some of his crop coincides with very high prices on the market. The crop is sold at Mkushi secondary school and Kapirimposhi, a nearby town connected by a very good tarmac road. Some buyers drive to these gardens to buy tomatoes as it is available all year round.

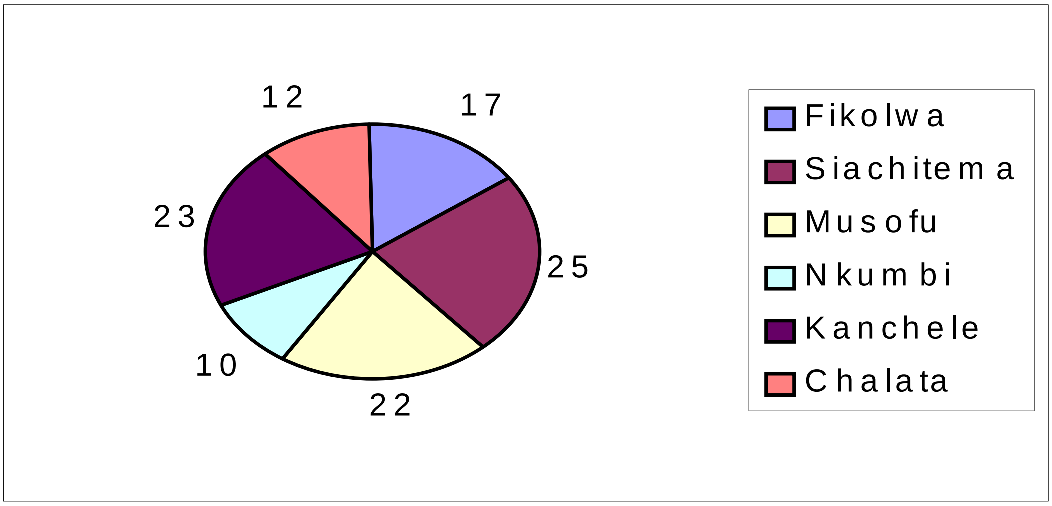


Figure 25: **Combined Crop diversities In Dambos (including upland rainfed cropping).**

6.4 Dambos as Safety Nets for Household Income and Food Security

Despite the problems encountered with marketing of vegetable crops at different times and locations, farmers are however able to sell Dambo vegetable crops at any time throughout the year unlike upland rainfed crops like maize, cotton and tobacco which are generally sold to out-grower companies once a year. The latter arrangement is often associated with long delays in transport and payments. This study established that out of the sixty farmers interviewed, 25% had not yet received cash from the sale of their upland produce, particularly cotton and tobacco, some six months after harvesting and marketing the crop on credit. This happens as a result of the buying companies being undependable. As indicated earlier, farmers in the Senanga district of Western Zambia also indicated this as a big contraint (Kwaw-Mensah, 1996).

Meanwhile their well-established Dambo vegetable gardens continued to provide in their daily household requirements. The farmers described a Dambo garden as a **"goose that lays the golden egg"**, a **"grocery"** or **"Lesa wa lusuba i.e the daily God "** who looks after each family member on daily basis.

Dambo garden produce is used for a combination of household consumption and sale. Those who buy the produce pay for it immediately, irrespective of whether they purchase it for their own consumption or for reselling it in order to generate income. Income from sale of the Dambo produce provides for other household needs as well. The fact that small but steady daily income comes from Dambos, they are considered as reliable socio-economic safety nets for household food security and other requirements.

Unlike staple grains, such as maize and sorghum, or cash crops, like tobacco and cotton, vegetables need to be marketed immediately when they are harvested and this offers the flexibility for households to obtain cash income at varying times during both the dry and wet seasons. The range of marketing possibilities was more flexible and greater than that of rainfed crops in terms of the times of the year at which they could be sold. One factor accounts for this i.e. there is not a fixed planting season, vegetables can be grown as needed. A household can decide on a monthly basis whether to grow crops for sale or home consumption or both. The fact they can use treadle pumps to reduce labour requirements enables them to expand gardens and offers them an opportunity to diversify cropping.

Dambo farming has been described as a very lucrative farming enterprise by all farmers in the pilot sites. This is mainly due to the following comparative advantages over upland farming as identified by farmers themselves (Table 20).

Table 20: Advantages of Dambo Land Use Compared with Upland Fields.

Dambo Garden	**Upland Field**
1.Offers crop security with full control of water.	**1.** Crop failure is common as there is no control over rains.
2.Yields are usually high and double cropping is possible.	**2**. Low yields and crop loss result due to drought.
3.Crop harvest can be spread over a period of time to provide food.	**3.** Have to wait long before harvest.
4.Produce are sold immediately after harvest.	**4.** Very an uncertain market for cash crops and have to wait for payments for too long.
5.Bridges the hunger period between November and January.	**5**. Food insecure between November and January.
6.Income and food provision is steady	**6.** An unsteady supply of food and income.

Because of the perishable nature of Dambo produce, the advantages of vegetable production is strongly dependent on marketing opportunities, as was also clear from section 6.3. Marketing opportunities are not only determined by markets, but also the availability of the necessary infra-structure to get produce to markets. According to Kwaw-

Mensah (1996) the Dambo vegetable farmers at Senenga in Western Zambia were able to produce excellent vegetables (see Figure 23) but they had serious marketing problems because of the poor infra-structure, i.e. bad roads and poor transport services. Consequently they could only produce limited quantities for sale at local markets at the school and hospital. This factor also manifests itself when glut occurs, i.e. when surpluses of one crop as a result of farmers following a similar cropping pattern and intensity. Such surplus crop has to be sold outside the village community over long distances to fetch a market outlet. Many times farmers have to travel long distances on bad roads transporting their produce on ox-carts. Sometimes the ox-carts break down and it could take several days to reach the markets where they wait for extra days before all the produce is sold. Such delays culminate in perishable crops like tomatoes getting rotten and damaged.

In the case of Senanga there was a potentially good market available in Lusaka, if only the roads and transport services were not so bad. In section 6.3 it was indicated that Musofu, Nkumbi and Fikolwa Dambos had the advantage of having a good market in the Copperbelt and being close enough to the tarmac road so that transport was not a problem.

At Mugabi Dambo in Chipata, Freshmark Limited sent trucks to Dambo gardens to buy vegetables for Shoprite Checkers supermarket. This created a good market for the Dambo vegetable farmers whose gardens have an access tarmac road to Chipata town. Moreover some farmers sell their vegetables across into Malawi, a neighbouring country that does not produce much vegetables.

6.5 Influence of Treadle Pumps on Farmers' Income from Dambo Gardens

Farmers' own incomes have increased since their involvement in the use of the treadle pump. This is attributed to the fact that their productivity has improved as a result of one or more of the following reasons:

- Labour savings between 60-75% by changing from irrigation using watering cans to using the treadle pump.

- Expansion of the area under irrigation as a consequence of gaining on time of irrigating a unit area of land has been made possible. Most farmers have increased the size of their gardens by an average of 150%.
- Income level before and after the treadle pump use is shown in Figure 26. The Figure also shows input expenditures associated with these levels of income.

Figure 26 indicates a distinct increase of cash income from Dambo gardens after the farmers began using the treadle pumps in the pilot sites. From farmers' interviews, it transpired that Morgan at Chalata, Moono at Kanchele and Charles at Musofu registered gross incomes of US$333 (ZK1,165,500), US$455 (ZK1,592,500), and US$257 (899,500) respectively in the 1997 irrigation season.

These farmers recall from their past cropping activities without using the treadle pump and coupled with little horticultural and water management knowledge, having attained gross incomes to a maximum of only US$33 (ZK115,500), US$66 (ZK231,000) and US$28 (ZK98,000) respectively. Thus income increases as a result of adopting the treadle pump technology are noticeable. The range of incomes after the treadle pump represents an increase in the order of sixfold to tenfold. It is therefore expected that the lifestyle of farmers will improve with time as is already evident in some respect. This is discussed in

the following section on the use of Dambo garden income. It should be borne in mind that for most of the farmers interviewed, these figures are on the conservative side for reasons that their monthly sales recalled, were on the low side because of not keeping records and that it is customary for farmers not to reveal all the figures in anticipation of external assistance from agents of change.

Comparing farmers' purchases for garden inputs, it occurs that farmers like Morgan and Moono have a good understanding of cultivation practices and pest and disease control as well as fertilizer requirements. These farmers spent more money to manage their gardens than others in the pilot sites (Figure 27). The same farmers obtained higher income from sales of their produce (Figure 26).

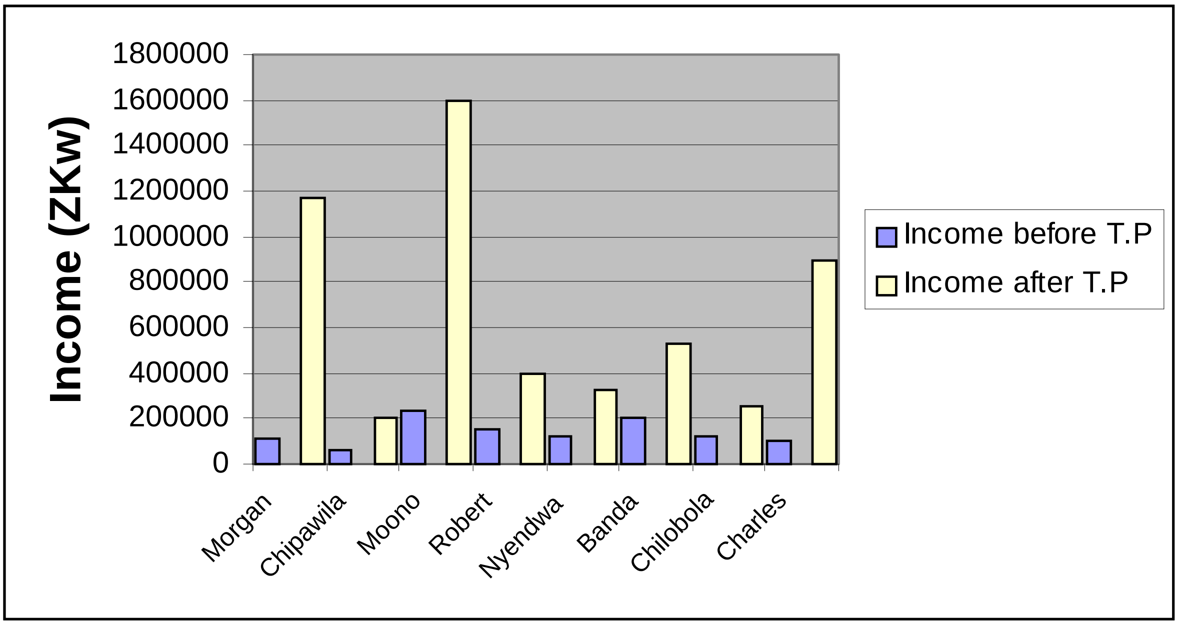


Figure 26: **Household Income From Dambos.**

It must be kept in mind that the advantages of the introduction of treadle pump technology can only be reaped if suitable markets are available and if this is supported by the necessary infrastructure to get the produce to the markets.

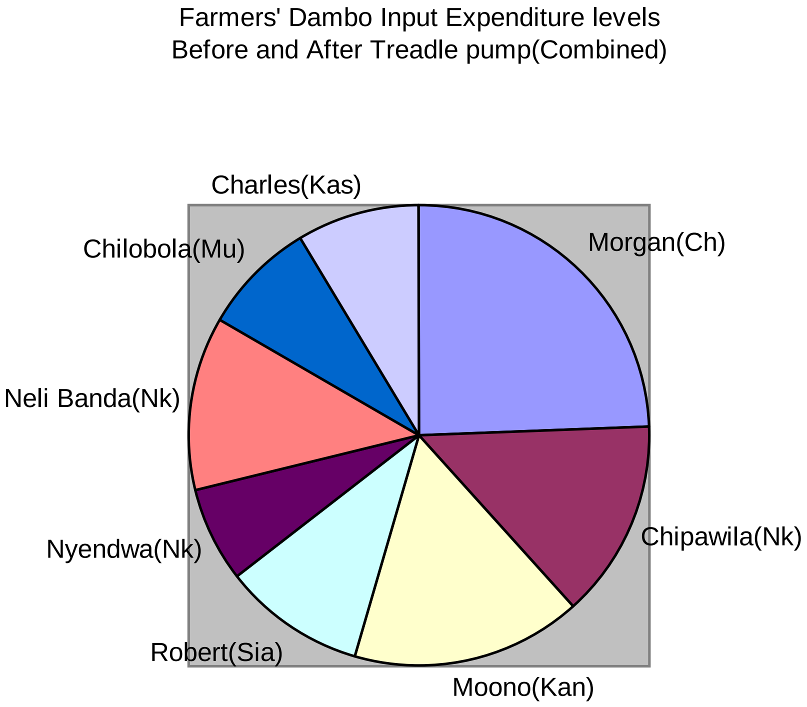


Figure 27: Farmers' Dambo Input Expenditure.

6.6 Use of Income from Dambo Gardens

Farmers in the pilot sites outlined several uses of income derived from vegetable gardens, some of which are outlined in Table 21.

Table 21: Usage of Dambo garden income by farmers in the pilot areas.

Description of Expenditure	**% farmers using income from vegetables for the purpose**	**% of total expenditure used for the specific purpose**
1.Purchase of seed, sprayers and chemicals for control of pests and diseases in vegetables.	93	30
2.Buying fertilizer for upland fields.	100	35
3.Bartering vegetables with staple maize for household consumption.	35	3
4.Buying work-oxen.	10	3
5.Buying mealie meal	5	10
6.Buying of soap, salt and clothing	100	10
7.Payment of school fees	100	7.5
8.Purchase of television, radio cassette, bicycle etc.	2	0.5
9.Bartering vegetables with chickens and goats.	65	1.0

For some of the outlined uses, it was possible to quantify how much had been spent by each farmer on specific Dambo garden inputs such as fertilizer, manure, pesticides etc.

It is clear from Table 21 that **all** the farmers interviewed, met their expenses on fertilizer for upland fields, daily household requirements (salt, soap and clothing) and payments for school fees from income generated from sales of Dambo garden produce. Nearly all the farmers (93%) also used income from Dambo garden produce to buy inputs for Dambo gardening. It is also evident that on average the farmers spent nearly two-thirds (65%) of the money generated by the sale of Dambo produce on the purchase of inputs for Dambo gardens and upland fields. This indicates that the livelihood of these farming families is dependent on crop production.

Bartering of vegetables with chickens and goats is done by 65% of the farmers, but it comprises only 1% of the total expenditure of vegetable garden income.

Bartering of vegetables for staple maize was done by 35% of the farmers, but it amounted to only 3% of the total expenditure of vegetable garden income. This indicates that in the area there are some farmers with surplus maize and inadequate amounts of vegetables, probably upland rainfed crop farmers without access to Dambo land. Conversely there are also some vegetable farmers who are not self-sufficient in regard to maize. Only 5% of the farmers bought maize meal but the expenditure on maize meal was 10% of the total expenditure. This is a very high proportion, considering the small number of farmers involved. It stresses the well-known fact that it is very expensive for small-farmers everywhere who are not self-sufficient in regard to staple maize to buy in maize meal. Overall these figures also indicate that 60% of the vegetable farmers were self-sufficient in regard to staple maize grain.

Only 0.5% of the total expenditure was spent for purchasing of television, radio cassette players and bicycles. Luxury items therefore appear to be far less important than requirements for crop production in the livelihoods of the farmers.

6.7 Gender Considerations and Labour Requirements in Dambo Gardens

In as much as male headed households worked with their families in Dambo gardens, it was recognized that certain chores were gender specific as outlined in Table 22. Although men have mostly acquired the treadle pumps, women and youths often operate them in the fields. Socio-culturally, irrigation, weeding, fertilizing and harvesting of vegetables are activities considered to be mainly for women. During the piloting phase, there were alleged fears and scepticisms that a woman who excessively used the treadle pump would not conceive because the movements during operation of the equipment shook the womb and affected her.

Such scepticisms have no basis. The scepticism was mostly mere speculation from the women's folk and has since disapperaed. There were no conflicts regarding specific roles men and women perform in preparing land and growing vegetables in Dambos.

Table 22: **Dambo Garden Gender Specific Activities (DGGSA)**

ACTIVITIES	**MEN**	**WOMEN**	**BOTH**
1. Operating treadle pump	***(+)	*	
2. Weeding	*	***	
3. Cultivating	***		
4. Fertilizer application			***
5. Harvesting	*	***	
6. Selling produce		***	
7. Keeping money		***	
8. Watering (irrigating)	**	***(++)	
9. Decision on cropping pattern	***		*
10. Attending organized farmer meeting			***
11. Purchase of inputs	***	*	
12. Planting or sowing	*	**	
13. Land ownership	***	*	
14.Garden fencing	***		

*** = frequently done by * = sometimes ** = often

(+) = After treadle pump introduction **(++)=** Before treadle pump

6.8 Cultural and Socio-Economic Aspects of the Treadle Pump

6.8.1 Cultural Aspects

The information in Table 22 depicts irrigation using a treadle pump to have shifted towards being done by men rather than women. Irrigation is always seen as a women's activity when watering is done by watering cans and buckets. The men often resisted watering the garden the whole day using laborious methods and left the task to women and their children. However due to reduced time of watering, men have since joined their families in irrigating using the treadle pump. Now women concentrate on weeding, fertilizing and harvesting the vegetables. The laborious activities of digging the Dambo land and fencing are left to the men while women do most of the Dambo activities that men think are light.

Men also encourage their wives to use this labour saving device which enables them increase yields and income by (i) applying adequate water to the crop and (ii) irrigating larger gardens with a diversity of crops. With these associated benefits, adoption rates have tended to increase at a rapid average rate of more than 800 pumps per year.

Women in Zambia operate the treadle pump without any traditional or religious restrictions such as those that prevail in Asian countries where a woman should not be seen exposing herself on the treadle pump (Alastair et al, 1991). In the latter countries women use the pump under a shelter or very early in the morning before sunrise or in the evening at sunset.

It is interesting to note that in Zambia, men are at the forefront in encouraging women to use the treadle pumps for irrigation since they have recognized its labour saving potential and antecedent opportunity to increase income. It is not clear if any antagonisms are offset by higher income. In Zimbabwe, the opposite obtains where men discourage their wives to expose their legs and hidden body parts while operating the treadle pump (Zirebwa, 2000).

The pump enables users to irrigate a 0.25 ha piece of land in less than three hours as compared to taking the whole day under traditional methods of watering. This gain in time would imply a feasibility to hire out the pump to other users. However, this has been rejected because farmers fear their colleagues' carelessness may lead to breaking of the pump. Moreover, if left unattended to in the field, the pump would be stolen by others. For these reasons, farmers in Zambia prefer individual pump ownership as opposed to group ownership.

Chancellor and O'Neil (1999) observed that the use of the treadle pump had greatly changed a woman's workload per day. They observed a case in Zambia where a farmer who had increased the cropping pattern by adding paprika in a vegetable garden where they previously grew only rape and tomatoes for their own consumption and for sale actually increased the workload for his wife who was in-charge of watering. Acquisition of a treadle pump by the farmer's wife greatly reduced her workload because her husband has now joined her to irrigate the crops using the treadle pump which is less labour intensive. This task was previuosly done by his wife alone. Due to the advent of the treadle pumps, male farmers have changed their cultural calendars of resting and attending to traditional ceremonies in the dry season, as they have to grow crops throughout the year.

6.8.2 Economic Impacts

Economic impacts of the treadle pump adoption as a technology for increased crop production could face dangers of depressed adoption due to glut on the market causing losses for the Dambo produce. As indicated earlier, local markets in the production areas would not absorb this increased production. Success would, therefore, be strongly dependent on markets elsewhere. As indicated earlier, this is not only dependent on the availability of a market, but also on the necessary infra-structure to get the produce to the market. The success achieved at Musofu, Fikolwa and Nkumbi Dambos is due not only being close to the Copperbelt market and a tarmac road, but also buyers or hawkers coming from the Copperbelt in an organized manner to buy produce on the farm, as indicated earlier.

In other areas this factor has been mitigated by the farmers themselves organizing regular markets, which attract a great number of consumers to participate in such a market system which has the format of an exhibition. This type of marketing is commonly practiced in Eastern province of Zambia in Chipata where farmers have established a Wednesday and Saturday market. Buyers of Dambo produce go to Dambo gardens with hired vehicles a day before the market day to buy produce for the sale the following day. An example of tomatoes being transported to markets is seen in Figure 28, whereas a typical market day is shown in Figure 29.

Another marketing system is contract farming, in which clients, e.g. Shoprite Checkers supermarkets, Chankwakwa limited, Sunripe Limited, and Rivonia companies enter into contracts with farmers to grow specified crops for them on an agreed forward price. In this way farmers of Chipata have improved their marketing arrangements. They are able to meet the required volumes by growing large areas using treadle pumps for irrigation. Examples of crops grown under contract Dambo irrigation include strawberries, irish potatoes, birds eye chillie, onion, tomatoes and green pepper. Figure 30 shows a crop under contract farming.

Figure 28: Tomatoes ready for transporting to an organized market (Mugabi Dambo).

Figure 29: A typical organized market for Dambo produce in Chipata.

Figure 30: A crop under contract farming at Indaba Dambo in Chipata.

The adoption of this technology by farmers has had some positive spillover effects on the nation's economy, including:

- Farmers are able to grow up to three crops in a year (300% cropping intensity) on the same piece of land, increase irrigated areas in the dry season and increase production per unit land area and per unit water. In this way they are not only able to bridge the dry season hunger-gap and achieve household food security, but also to provide much needed vegetables to mining and urban communities on a sustained basis. This reduces the country's reliance on imports of such produce and saves foreign exchange.
- Employment is created through the supply chain of pump manufacturers, retailers and users (farmers) who employ artisans at manufacturing points and carpenters to produce the wooden accessories.

- Employment creation at farm level because families cannot handle the labour required on the larger areas cultivated.
- Increased income at household level. Farmers have been able to increase their annual net income from a meagre US$125 without a treadle pump to US$850 - US$1,700 on a 0.25 ha piece of land with treadle pump growing three crops in a year.
- Creation of employment at the output side for buyers (merchants/hawkers) and transport contractors who trade and transport the produce.
- The treadle pump is economically viable and beneficial, as it does not depend on petrol, diesel, gasoline and electricity to operate it. These sources of energy are expensive and not always readily available.

6.9 Access to Land in Dambos

There were no restrictions to access to Dambos at all the sites studied. Men and women had equal access to Dambos. Table 23 shows that in the areas studied between 22.7% and 100 % of households had access to Dambo land. Much more Dambo land was still available for occupation. For some reasons a large proportion of the people had not acquired any piece of land at some Dambos, i.e. Chalata, Siachitema and especially Fikolwa. Although laziness to till Dambo soil was cited as a reason for low utilization and access to the Dambo at Fikolwa, this study has established that on account of high soil acidity, this Dambo does not support a wide range of crops and is, therefore, less utilized. At Musofu and Nkumbi practically all households and at Kanchele 80% of the households accessed Dambos and yet the utilizaed proportions of these Dambos were very low. It is noteworthy that the population densities at these Dambos seem to be lower than where small proportions of the farmers accessed Dambos.

Dambo soils are perceived to be very difficult to till unless when moist. With the treadle pump, it is possible to apply adequate water in the dry Dambo zones and make such land ready for tillage. Further more, upper grassland zones of Dambos are often away from shallow watering points within a Dambo and one has to dig deeper than 3 m to access water within this zone. Lifting water from such depth by the bucket and rope method is tedious and hard work. A treadle pump has made it possible to reticulate water from watering points further away to this water gardens in this zone or to abstract water more easily from deeper wells in this zone.

Table 23: Information on Dambo utilization in the study areas.

Location	**Number and % households accessing Dambos**	**Average Garden Size (ha)**	**Dambo land area cultivated (ha)**	**% of Dambo cultivated**	**Presence of Stream**
Fikolwa	45 (22.7%)	0.10	4.50	5	Yes
Chalata	87 (50%)	0.50	43.50	21	Yes
Musofu	65 (100%)	0.25	16.25	15	Yes
Nkumbi	36 (98%)	0.10	3.60	16	Yes
Siachitema	65 (50%)	0.50	32.50	29	Yes
Kanchele	55 (80%)	0.50	27.50	21	No
Total =	**353**	**0.32**	**127.85**	**-**	**-**

The above analysis shows an estimated number of 353 households accessing Dambos for cultivation in the two districts of Mkushi and Kalomo. It is further estimated that about 128 ha are under vegetable production using either buckets and watering cans or, to some extent, treadle pumps.

Most farmers indicated that they acquired land in Dambos by inheriting it from relatives while village headmen allocated it to a few. Once allocated, they are free to pass the land parcel to the next of kin.

6.10 Influence of the Introduction of Treadle Pumps on the Adoption of Irrigation

It is difficult to estimate the adoption of irrigation because of the introduction of the treadle pumps, as most farmers in the pilot areas already practiced irrigation, using watering cans and buckets to abstract water from shallow wells, before introduction of the pump. What is evident, however, is that introduction of the pumps led to adoption of better methods of lifting water using treadle pumps, good irrigation practices with nice farm layouts for water reticulation, improved shallow wells and better horticultural practices.

For example, at Musofu farmers who could not easily control the seepage water are now able to manage this through training in irrigation field layouts and in using furrows and small ditch drains for easy operation of the treadle pump. Using the treadle pump, they have also been enabled to utilize the upland parts of the Dambo which they could not irrigate using watering cans because of the distance from the water sources. In these zones, crop productivity is very high due to better soil aeration and good drainage as a result of light textured soils unlike the heavy clays in the central parts of the Dambo and also because of their position in the landscape. Farmers in Chalata also share this experience.

Farmers in Kanchele and Siachitema have been able to expand their gardens as a result of owning the treadle pump. They have, however, been unable to irrigate adequately due to collapsing wells which, by the end of this study, had just been lined with concrete rings. This having been their major constraint, farmers are confident of achieving even better results in subsequent seasons, as the recharge will have improved to levels where the treadle pump can be used without drying these wells.

6.11 Use of Treadle Pumps for Activities other than Irrigation

During the present study it was found that treadle pumps are used not only for irrigation but also for other purposes. These include *inter alia* the following:

- Women use the treadle pump to draw water for domestic purposes sush as; drinking, washing and bathing children. This has reduced the long distances they walk to fetch water from streams and rivers and give them more time for other chores, including farming activities such as weeding.
- Women use the treadle pump to draw water for domestic purposes sush as; drinking, washing and bathing children. This has reduced the long distances they walk to fetch water from streams and rivers and give them more time for other chores, including farming activities such as weeding.
- The pump is gaining importance in construction activities requiring water and in dewatering during well lining.
- Farmers also use the treadle pump to draw water from either a well or the wet central zones of the Dambo to the uppergrassland zone for provision to livestock.

6.12 Conclusions And Recommendations

1. The capability of the treadle pump to contribute to household food security has been demonstrated in the pilot areas where farmers'incomes have increased by

between sixfold to tenfold when compared to cultivation without a pump.

2. It is evident that operation of the treadle pump is done by men, women and children. It is therefore recommended that training in the use of treadle pumps should be directed at both men and women, who can in turn train their children.
3. It is recommended that the training for use of the pump should be emphasized to both men and women with their children as they all use the pump.
4. Time savings on irrigation as a result of using the pump have resulted in increased areas under irrigation.
5. Given that each pump commands an average of about 0.25 ha per crop cycle, irrigating two crops per year, there is about 1250 ha currently irrigated by small-scale farmers using the treadle pump.
6. Crop diversity in Dambos is a signal of increased use of these environments for crop production.
7. Farmers' livelihoods are fast changing positively through visible improvement in terms of nutrition and increased income at household level.
8. Introduction of treadle pumps created new employment opportunities, both on the input (manufacturing of pumps) and the output (marketing and transport) sides.
9. Before advocating large scale introduction of treadle pumps in an area it must first be ascertained whether the necessary markets and infrastructure exist, or can be put in place, to absorb the surplus produce that will be generated. This is a key component of any land use planning exercise.

CHAPTER 7

CLAY POT SUB-SURFACE IRRIGATION AS WATER-SAVING TECHNOLOGY FOR SMALL-FARMER IRRIGATION

7.1 Introduction

The most common problem in tropical and sub-tropical Africa in the last two decades has been lack of water due to droughts. This has brought about food insecurity at household level as a result of low food and fibre production to meet the demands of the ever increasing population in these regions. It is therefore prudent for scientists to think of conservation and efficient utilization of water to maximize production per unit volume of the limited available water resources. Water scarcity is never felt if it is needed only for few plants, especially where water is easily available and is in abundance. However, if many plants have to be watered and the water source is far away, regular watering may sometimes become a problem. Even if watering is accomplished, much of the water may be lost due to evaporation, especially under very hot and dry conditions, or deep percolation and seepage beyond the rootzone in sandy soils. These problems are more acute in arid areas and in places like the Western province of Zambia where the sand content in the soil is very high. A close look at these arid and semi-arid areas reveals a serious lack of tree plantation crops such as coffee, tea and citrus respectively. Such crops require particular attention with regard to water availability for irrigation especially in the first year of establishment if these trees have to survive.

A simple, but efficient, technological device (the clay pot) which entails creation of rural employment, savings on scarce water resources but maximizing yield and a reduction in irrigation frequency and total amount of water to grow crops has been introduced and tested by the author at the National Irrigation Research Station (NIRS) in Mazabuka district. Sub-surface irrigation using unglazed porous clay pots is an ancient method still practiced today in several countries, notably India, Iran, Brazil (Power, 1985; Yadav, 1974;

Anon, 1978 and 1983) and Burkina Faso (Laker, 2000; personal communication). The technology is comparable of sub-surface drip irrigation. Water is made available as crops need it. The system has been used successfully for the irrigation of vegetables, orchards and woodlots.

Sub-surface irrigation employing indigenous clay pots made by rural women has been found to be appropriate and relevant for use by small-scale farmers in crop production without any resultant adverse effect on the soil in terms of salt accumulation as no waterlogging occurs. Weeds are suppressed advertently, thus reducing transpiration losses of irrigation water through weeds, as the surface soil layer remains dry throughout the growing season (except after a rain), a factor which also reduces evaporation losses of irrigation water from the soil surface.

This chapter gives highlights on the merits, demerits, economics and feasibility of the system for expansion under small-scale production. The principles of operation, maintenance and fertilization are elucidated. Future scope for adoption in sustainable small-farmer irrigated agriculture presented, with specific focus on vegetable and tree crops.

7.1.1 Objectives

(1) To compare the water requirements and yield responses of some vegetable crops grown under clay pot sub-surface irrigation and the conventional watering can.

(2) To establish the water use efficiencies of these vegetable crops and derive irrigation intervals and water savings with the clay pot system, compared with the conventional watering can irrigation system.

(3) To assess the suitability of clay pot irrigation to small-scale farmer-irrigation with regards to system performance and crop adaptability.

(4) To establish the radius of a wetting front for water distribution from clay pots in a sandy clay loam soil.

7.1.2 The Clay Pot as Sub-surface Irrigation

The clay pot used for irrigation is an unglazed indigenous earthen pot which has many micropores in its wall. The microporous wall does not allow water to flow freely from the pot, but guides water seepage from it in the direction where suction develops. When buried neck deep into the ground, filled with water and crops planted adjacent to it, the clay pot effects sub-surface irrigation as water oozes out of it due to the suction force which attracts water molecules to the plant roots. The suction force is created by soil-moisture tension and/or plant roots themselves.

7.2 Experimental Procedures

7.2.1 Site Selection

The experiments were conducted at Noole Dambo, located in a semi-arid area of Agro-ecological zone II of southern province of Zambia with an average annual rainfall of about 600-800 mm. The Dambo is classified as an upland Dambo.

The upper grassland zone of the Dambo was selected for setting up the experiment because of its good drainage in the rain season and difficulty to transport water from wet Dambo zones to irrigate citrus and vegetables grown in this zone during the dry season. Tree crops particularly do well in the upper grassland zone, as flooding is not a limiting factor at any time of the year.

7.2.2 Materials and Experimental Methods

A completely randomized block design with three replications was used for all the vegetable and cereal (maize) crop trials. Study plots measuring 4 m x 1 m were prepared by cultivating the soil to a fine tilth with a hand hoe after the soil was brought to field capacity. Beans, cauliflower, cabbage, maize, onion, rape and tomato were evaluated in this experiment.

Clay pots with a capacity of 5 liters each and made by rural women (see section 7.4) were installed at 0.5 m intervals in the study plots by burying them neck deep in the prepared seed beds. During irrigation a clay pot was filled with water and then covered with a ceramic lid. Lids made of wood are avoided as they are easily damaged by termites. The covering of clay pots prevents evaporation losses of water from them. It also prevents the possibility of rodents and other small animals drinking from the pots or falling into them. Covering of the pots also prevents soil being washed into them during rains or being deposited in them by wind.

Eight clay pots were required for each configuration in a given seed bed. Twenty one such seed beds were prepared and except for beans which was directly seeded, seedlings were transplanted adjacent to either sides of the clay pots in such a way that the first seedlings and last seedlings in a given study plot were 45 cm away from the clay pot and 10 cm away from the edge of the bed. The crop spacing in this configuration was as per horticultural recommendations of 30 cm x 90 cm for cabbage, cauliflower, maize, rape and tomatoes. Beans and onion were spaced at 10 cm x 15 cm drilled and transplanted in rows respectively between and on the side of the pots (Figure 31).

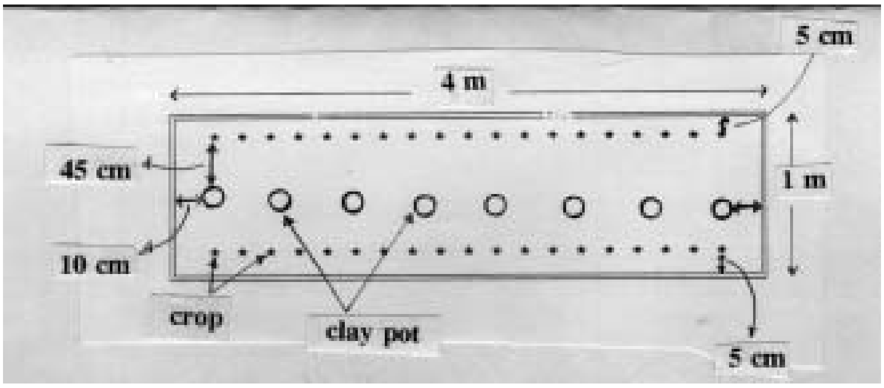


Figure 31: **Field layout configuration for clay pot irrigation.**

Control plots were established, which had similar arrangement and used the same crops but without clay pots. Irrigation was done by the traditional conventional method which employs irrigating with watering cans.

Water manometer tensiometers were used to determine the radius of the wetting front from clay pots and when to irrigate. Two tensiometers were installed per plot at a depth of 30 cm and distances of 20 cm and 45 cm away from the clay pot. In the case of the control plots, tensiometers were installed at distances of 20 cm and 45 cm away from the plant. Three random locations were selected in each of the replications and readings were taken every day in the morning and afternoon. The tensiometer at a distance of 20 cm away from the clay pot or a plant in the control plots and installed at 30 cm depth was used as an index instrument for monitoring irrigation cycles. The tensiometer located at 45 cm distance from the pot was used to check the wetting front from the clay pot.

Clay pots were refilled every time they reached a 50% depletion level and /or when index tensiometers recorded between -20 kPa and -40 kPa, whichever occurred first, in order to ensure that:

- The discharge rate was fairly constant.
- The soil moisture levels around the pots were maintained at high enough levels to avoid soil-induced water stress in plants.

- Pot clogging due to salt accumulation, caused by possible prolonged drying of the pots, was avoided.

The control plots were irrigated every time as soon as crop stress was observed and/or when index tensiometer readings recorded between -20 kPa and -40 kPa.

Yield was measured by weighing actual harvested produce from the crops in the study plots on a standard hanging scale. The yield was measured in kilogrammes but translated to ton/ha for both treatments. Results by the Vegetable Research Team (VRT, 1996) on water requirements and yields of the same crops irrigated by sprinklers were used to compare with those obtained from this trial.

In view of the difficulty to irrigate and establish tree crops under conventional irrigation systems that use buckets or watering cans, the use of clay pots was tried with coffee, citrus and mexican sugar apples on an observational basis. Yield results are not reported here as the crops take a long time to start fruiting. However, experiences elsewhere are discussed in relation to observations made in this observational trial.

7.2.3 Statistical Analysis of Yields

A statistical computer package called AGSTATS was used to analyze the statistical significance in yield differences (Russ *et al*., 1987).

7.3 Results And Discussion

7.3.1 Yield Responses

Yield data for clay pot, sprinkler and conventional watering can irrigation systems respectively are presented in Table 24.

Table 24: Yield data (ton/ha) for various vegetable crops under clay pot, conventional watering can and sprinkler irrigation systems respectively.

Crop	**Clay-pot**	**Watering can**	**Sprinkler***	**LSD(5%)**	**CV(%)**	**SIGNF**
1. Beans	5.12	4.55	4.85	0.80	7.29	NS
2. Cabbage	56.82	60.07	62.00	5.58	4.13	NS
3. Cauliflower	**23.03**	**16.67**	16.67	**1.58**	3.70	**SNF**
4. Maize	**14.15**	**8.97**	9.27	**1.78**	7.27	**SNF**
5. Onion	36.13	36.62	35.71	2.73	3.3	NS
6. Rape	**33.17**	**26.37**	22.87	**2.05**	3.29	**SNF**
7. Tomato	45.33	40.40	47.17	8.23	8.20	NS

SIGNF = Significance; SNF = Significant; NS = Not Significant

The sprinkler irrigation experiment was not part of this study and conclusions regarding significant differences should not be drawn for it. The data are included for broad comparison purposes only. Sprinkler irrigation data from VRT (1996).

Although they are from different experiments, the remarkably close agreements between the yields obtained with the conventional watering can irrigation technique and those obtained with sprinkler irrigation for **all the crop** (Table 24) are noteworthy. This reinforces the finding of Kwaw-Mensah (1996) in Senanga district of Western Zambia that small-farmers are able to grow excellent vegetables with very simple techniques. This is well illustrated by the photographs from his study presented here in Figure 32 a,b.

32a: Cabbage

32b: Tomato

Figure 32(a, b): Cabbage and tomato grown by small-scale farmers using simple watering techniques.

In the present study statistically significantly higher yields with the clay pot irrigation system than with the watering can system were obtained for three of the seven crops, viz. cauliflower, maize and rape (Table 24). The yields with the clay pot system for these crops were also substantially higher than for the sprinkler system, although they cannot be compared statistically. In no case did the clay pot system give significantly lower yields than the watering can system or substantially lower yields than the sprinkler system. Even more noteworthy than the statistical significance of the increases in yield with the clay pot system over the watering can system are the large magnitudes of these increases on a percentage basis. For cauliflower it was 38%, for maize 58% and for rape 26%.

7.3.2 Crop Water Requirements and Water Use Efficiency

Crop water requirements and water savings by using the clay pot irrigation as compared to the conventional watering can system are presented in Table 25. From the results presented in Table 25, it is observed that water savings between 50% and 70% are achievable with the clay pot irrigation system as compared to the conventional watering can system where water is applied onto the soil surface, causing soil crusting and inducing excessive evaporation. Crusting is responsible for low infiltration of water in the soil, poor aeration and slow crop development under conventional systems. On the other hand aeration and soil moisture retention is very good under the clay pot sub-surface irrigation system.

Evidence from index tensiometer readings showed that at 30 cm depth the soil around clay pots remained relatively close to field capacity during each irrigation cycle, with the tensiometer reading varying between -15 kPa and -20 kPa whilst the tensiometer located 45 cm away from the pot recorded between -20 kPa and -40 kPa. The irrigation cycle was thus found to be 7 days for clay pot irrigation and 4 days for conventional watering can systems.

Table 25: **Seasonal crop Water Requirements of some Vegetable crops under Clay Pot and Conventional Watering Can Irrigation Respectively and Water Savings by Using Clay Pot Irrigation Instead of the Watering Can System.**

Crops	**Clay-pot Irrigation (mm/season)**	**Conventional Watering can (mm/season)**	**% Water savings**
1. Beans	203	450	**55**
2. Cabbage	45	150	**70**
3. Cauliflower	250	500	**50**
4. Maize	200	500	**60**
5. Onion	67.5	225	**70**
6. Rape	180	400	**55**
7. Tomato	195	650	**70**

Peculiarly low water requirements were observed under both the clay pot and the conventional irrigation systems for cabbage and onion, a head and bulb forming vegetable respectively.

Tomato, cauliflower, beans and maize appear to demand more water with requirements of 650 mm, 500 mm, 450 mm and 500 mm respectively under the conventional system, compared to relatively much lower demands of 195 mm, 250 mm, 203 mm and 195 mm under clay pot irrigation respectively. The vast reduction in water use by crops under clay pots did not, however, reduce yields (Table 24).

By combining the data in Tables 24 and 25, water use efficiencies can be calculated (Table 26). Water use efficiencies can be expressed in two ways, i.e. either as amount of water used per unit yield harvested or the yield per unit water used. Both of these are given in Table 26. Higher water use efficiency is where a smaller volume of water is used to produce a unit yield or where a higher yield is obtained per unit water used. It is observed from Table 26 that all crops grown under the clay pot sub-irrigation system manifest **much** higher water use efficiencies than those under the conventional system. This means that crops under clay pots only require less water to produce a unit biomass yield as compared to the conventional traditional watering can irrigation system or produce a higher yield per unit water applied.

Table 26: Comparative water use efficiencies for various vegetables under clay pot and conventional watering can irrigation systems.

Crops	**Clay pot**			**Conventional Watering Can**		
	(m^3/ton)	**:**	**(kg/mm)**	**(m^3/ton)**	**:**	**(kg/mm)**
1. Beans	396.5	**:**	25.2	989.0	**:**	10.1
2. Cabbage	7.2	**:**	1262.7	25.0	**:**	400.5
3. Cauliflower	108.6	**:**	92.1	299.0	**:**	33.3
4. Maize	141.3	**:**	70.8	557.6	**:**	17.9
5. Onion	18.3	**:**	535.3	60.7	**:**	162.8
6. Rape	54.3	**:**	184.3	151.7	**:**	65.9
7. Tomato	42.0	**:**	215.4	160.9	**:**	62.1

The surface soil in clay pot irrigation systems remains dry thereby reducing weed prolification and direct evaporation of water. However, this does not mean that the clay pot which wets only part of the soil volume in the field reduces water consumption by plants but rather cuts back on the waste of water due to evaporation, deep percolation and competitive consumption of water by weeds. These reductions on water wastage enhance the crop water use efficiency.

The conventional system whose soil surface is usually heavily wetted at each irrigation cycle remains vulnerable to weed infestation. Weeds compete with crops on water and nutrient consumption and direct evaporation of water from the sun increases with a wet surface. These factors drastically reduce crop water use efficiencies.

Root development and root distribution within the wetted zone are important factors in regard to water use efficiency. At the end of the trial, it was found that the tomato plants had formed mats of fibrous roots all around the clay pot. In this way the crop enjoyed direct abstraction of water as it oozed out of the pot under atmospheric pressure head. Similarly rape, cauliflower and maize exhibited rooting systems that ramified the soil deeply, but were confined within the wetting zone of the pot.

The capability of the roots to absorb water depends on their surface area, which is a function of their length, number and diameter. Thin roots have relatively high surface area per unit cross-sectional area or per unit of root mass (Taylor and Fenn, 1985). A concentration of thin fibrous roots in the confined volume of irrigated soil under clay-pots will therefore have a tremendous capacity to supply water to the above ground canopy due to increased root surface area, a relative low dependence on water movement to the roots in the soil.

Observations have also shown that cabbage and onion have shallow rooting which is also not fibrous. Despite their shallow, non-fibrous roots, both cabbage and onions had absolutely incredibly high water use efficiencies. Although yields of cabbage and onion were slightly lower under clay pot irrigation than the conventional system, their water use efficiencies were highly superior with this system because the rootzone remains moist whereas it quickly dries up under the conventional watering can irrigation system.

7.3.4 Application of Clay Pot Irrigation to Perennial Crops

Trial plantings of fruit trees (Mexican apple and citrus) and a plantation crop were made to compare the suitability of clay pot irrigation as an alternative to conventional small-scale irrigation for these crops. Comparisons were made in terms of early growth rate and mortality rates of young trees. The system was not evaluated in terms of yield, because that would require growing the trees for a number of years. The clay pot system, as observed in mexican apple and citrus tree seedlings, performed very well in terms of growth and establishment as compared to the slower growth rates and high mortality rates experienced with conventional plantings four months from transplanting in August 1996 (Tables 27 and 28).

Table 27: Height and stem diameter of Mexican apple and Citrus plants as affected by different treatments.

Treatment	**Height**			**Stem diameter**		
	Initial (cm)	**Final (cm)**	**Increase (%)**	**Initial (cm)**	**Final (cm)**	**Increase (%)**
Mexican apple						
Clay Pot	**20**	**37.50**	**87.5**	**0.30**	**0.54**	**80.0**
Watering Can	**20**	**23.84**	**19.2**	**0.25**	**0.40**	**58.0**
Citrus						
Clay pot	**30**	**57.00**	**90.0**	**0.25**	**0.45**	**78.5**
Watering Can	**30**	**35.55**	**18.5**	**0.25**	**0.39**	**55.2**

Table 28: Mexican apple and Citrus seedlings mortality rates during establishment in Clay Pot and Conventional Watering Can Irrigation systems.

Treatment	**Seedling establishment plant count**		**Mortality Rate (%)**
	Initial plant count	**Number of plants replaced due to mortality**	
Mexican apple			
Clay pot irrigation	**50**	**3**	**6.00**
Watering Can irrigation	**50**	**18**	**36.00**
Citrus			
Clay pot irrigation	**80**	**1**	**1.25**
Watering Can irrigation	**80**	**13**	**16.25**

Fast tree growth and absence of water stress was evident in the early stages of establishment. Clay pots also ensure better establishment of trees as plant mortality is reduced to reasonable levels with more plant seedlings surviving. The system also reduces the frequency of irrigation during establishment of tree plants as well as the total amount

of water applied. Plant height increases of 87.5% and 90% for mexican apple and citrus, respectively, were observed in clay pot irrigation compared to 19.5% and 18.5%

increases for the same crops under conventional watering can (Table 27). Higher stem growth rates are also observed for clay pots than the conventional watering can. Table 28 illustrates better tree seedling establishment under clay pot irrigation (94% - 98.75%) than the conventional watering can (64% - 83.75%).

In India, Gupta *et al*. (1988) found similar trends in water utilization by plants grown in double walled clay pots compared to conventional planting. In their studies they observed that one month old Ziziphus memmularia - a thorny tree which bears edible fruits and grows in association with Acacia species, showed 85.7% height increase from double walled clay pots as opposed to 17.9 % in the latter. Observations on stem girth indicated the same pattern, with 78.1% increase with clay pot irrigation, against 55% increase with conventional methods. It was observed that in double walled clay pots called **'Jaltrip',** water is well regulated and maintains a constant soil moisture around the rootzone. This accords with my observations in citrus and mexican sugar apple fruit trees. Ziziphus memmularia is commonly known as Muchechete tree.

Gupta *et al*. (1988) believes that under conventional planting (pit hole planting) and watering methods, soil water levels remain high only for a short period after watering and dries out quickly to levels where it is no longer readily available to plants. Seedlings planted in double walled clay pots are later transplanted to the field where pit holes are dug. They grow in-situ during the establishment stage and their roots would remain pot bound if left for longer periods of time. The fact that the double walled clay pot has to be filled with soil as a medium for seedling growth, however, make them cumbersome to work with.

In Burkina Faso clay pots are used to irrigate trees, including eucalyptus trees grown in communal woodlots (Figure 33)

Figure 33: Irrigation of eucalyptus trees using clay pots in communal woodlots of Burkina Faso.

***(Note clay lid in the hands of person at right hand:* Photo by Prof.M.C. Laker)**

The clay pots have been found to be appropriate for use in Dambo margins for growing fruit trees without any attendant problems of regularly irrigating. This is possible because of their ability to save water and supply it to crops efficiently. Once established, the trees have their root system deep enough to extract water from the capillary fringe above the water table which is usually within 2-3 m depth in this Dambo margin.

7.3.3 Fertigation in Clay Pots

In clay-pot irrigation, fertilizer application can be done in the irrigation water wherein it dissolves and is absorbed by the plants as a solute during the process of water oozing out of the clay pot. It is possible to apply less fertilizer under clay pot irrigation as compared to the conventional system where not all the fertilizer applied to the soil is used by the plants as some remain fixed to the soil while some is leached beyond the root zone.

Because of this efficiency in fertilizer uptake under clay pot irrigation there is a need to adapt fertilizer applications to the needs of the plants. It was observed that applying the same amounts of fertilizer as for conventional applications in clay pot irrigation systems, had adverse effects, eg. scorching and killing of seedlings, particularly in vegetable crops. Half of the recommended doses for conventional systems proved to be suitable for the clay pot irrigation system. ***This is a tremendous advantage, since high fertilizer costs often pose severe limitations to small-scale resource poor farmers.***

7.3.4 Advantages and Disadvantages of the Clay Pot Irrigation System

7.3.4.1 Advantages of the System

The clay pot sub-surface irrigation has been found to have multiple advantages as a technology for small-scale farmers, particularly for rural development. The following advantages accrue in this system:

1. Since clay pots are made by rural women they create employment and opportunities for small-scale home industries to manufacture them in rural areas. This will help generate rural income for household food security.
2. They are affordable. A 5 liter capacity clay pot costs US$0.25.
3. Clay pot irrigation allows a farmer to raise seedlings **in situ** instead of transporting them from nurseries. Clay pots are installed directly where seedlings are to be planted and this allows a farmer to plant the seed next to the clay pot where it germinates and gets established.
4. The system is suitable for vegetables as well as perennial horticultural orchard or plantation crops and woodlots.
5. Water savings of 50-70 % are realized, particularly for vegetable crops. Loss of water due to deep percolation beyond the rootzone is reduced if not avoided.
6. Soil moisture is always available almost at field capacity giving the crop full security against water stress.
7. The system inherently checks against over-irrigation.

8. The much smaller quantities of water and less frequent watering required, reduce the amount of labour required for irrigation tremendously.
9. Much less labour is required for weeding since weeds do not prosper, as the soil surface remains dry throughout the growing season.
10. Domestic water effluent from kitchens can easily be recycled and used in clay pot irrigation in backyards. The water used for cleaning utensils in the kitchen can be used to refill the pots in a backyard garden. This saves on scarce water and reduces the need to use fresh water.
11. It saves on the amount of fertilizer to be applied per unit area of land if the fertilizer is applied in clay pots and is later absorbed as solute via water movement to the plants.
12. The soil of the seedbed under the clay pot system does not get sealed due to water impact but remains loose and well aerated.
13. The clay pots can be installed on undulating ground.

7.3.4.2 Disadvantages of the System

The following disadvantages were observed in fields where clay pots are used:

1. The clay pots can break if dropped while working with them during installation.
2. If left dry for a long time, the pores will clog due to salt accumulation and precipitation.
3. Discharge rates may vary due to poor sand B clay mixture being used during the manufacturing of clay pots that may not guarantee a good porosity that will give adequate outflow of water to match plants' water demand.
4. Very heavy soils may not effect a good wetting front. Medium textured soils such as loamy sand, clay loam and silt loam are good.

5. The system may clog as porosity declines with time during prolonged use. When porosity progressively decreases unabated, it becomes difficult to cope with high crop water requirements.

7.4 Manufacturing Of Clay Pots

The clay pots are made from a mixture of clay and sand in the ratio of 4:1 and with an effective porosity ranging from 10-15%. The clay pots are made by rural women using their hands to mould them into different shapes, i.e. cylindrical/round with somewhat flat bottom.

After they are made, glazing is not done so as to retain their natural porosity i.e. the walls remain micro-porous. The pots are then tempered by burning them in a pit fire from firewood at undetermined temperature. Small-scale earthen-ware manufacturers use kilns to temper such ceramic pots at 1200°C. This is done in order to eliminate the swelling and shrinking properties of clay, which would cause cracking of the pots. Women believe that the type of clay used to make the pots is very important and it requires an experienced old woman to identify clay that would not crack unduly during the tempering process and indeed when installed under field conditions. Figure 34 shows clay pots after going through the manufacturing process and ready for use in the field.

Figure 34: Clay pots ready for installation in the field.

7.5 Principles Of Operation

Figure 35 shows a clay pot in operation when installed neck-deep into the ground and filled with water.

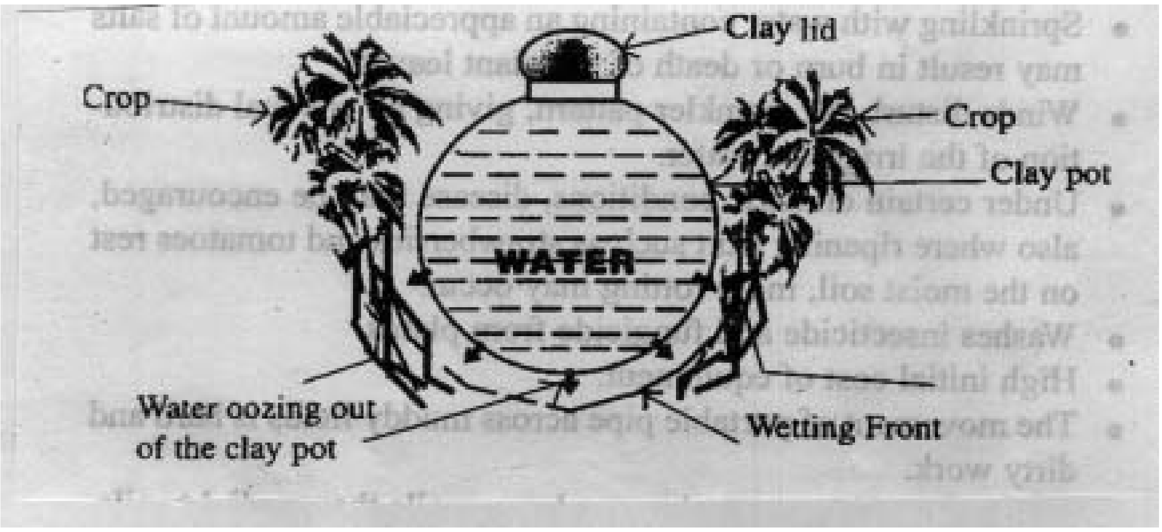


Figure 35: Clay Pot Operation Principles.

When neck-deep into the ground, filled with water and their mouths covered with a clay lid, the inside part of the pot is under atmospheric pressure. The atmospheric pressure, soil tension and root-suction tension will force the water to ooze out of the pot, forming a wetting front that wets the soil surrounding the clay pot. The wetting process continues until the soil moisture status is in equilibrium. As long as there is water uptake by plants, water continues to flow out of the pot. It is by this mechanism that advantage to irrigate crops by planting them on the side of the pot should be taken. Crops planted in seedbeds installed with clay pots take up this water to satisfy their requirements up to maturity. The wetting front depends on the soil texture. Sandy soils do not allow water to move horizontally away from the point source much but responds more to the vertically acting gravitational force.

7.6 Maintenance Of Clay Pots

It is important to keep the system well maintained if its potential benefits have to be realized fully. In order to achieve this the following points ought to be followed:

1. Always keep the pots wet by not allowing water to deplete beyond 50% capacity. This will counteract possible clogging and enhance water flow out of the clay pot.
2. Long irrigation intervals entailing total depletion of the pots should be avoided as this will encourage clogging particularly if the water is highly carbonated.
3. When not in use, the pots should be removed from the soil, washed and dried to avoid clogging of micro-pores. A safe storage place should be found so that undue breaking does not take place.
4. Hydrochloric acid should be used to unblock the system once clogged.

7.7 Sustainability And Economics

The clay pot technology is sustainable since the pots are made from readily and locally available materials which are in abundance. They are low-cost and are made by rural women whose activity to manufacture them at village level offers possibilities of rural income generation at household level.

At a cost of US$0.25 they are affordable by the majority of end users. When properly used and maintained, they can be re-used year in and out for a period of up to 5 years. The fact that very little water is required to raise crops, offers a high potential for their demand particularly in regions with scarce water. No skill is required to operate and maintain the system. The low fertilizer requirements, as compared to conventional recommendations, greatly enhances the economic benefit of the system.

7.8 Optimizing The Clay Pot System By Combining It With Treadle Pump Technology

Although the clay pot requires much less water than the traditional watering can system, it is still relatively tedious and requiring a lot of labour if water extraction is done by means of a rope-and-bucket system and filling of pots is done by carrying water to them with watering cans. In the previous chapters it was shown that treadle pumps provide a much more efficient and less laborious system for abstracting water from wells or rivers than the rope-and-bucket system. By connecting a hosepipe to the treadle pump, water can be delivered at the point where it is needed. The pots can be filled directly from the hosepipe or watering cans can be filled close to the point where they are used to fill pots. Combining the two technologies in this way can clearly optimize the clay pot system.

7.9 Conclusions

1. Clay pot sub-surface irrigation is a drip irrigation system by way of its water application to the plants. Water oozes out through the micro-pores of the pot and wets the surrounding soil. The crops grown around the pot take up the water as they need it.
2. It has been found that as long as the water is not completely depleted in clay pots, it will be in continuous phase of moving out of the pot as long as water uptake by a crop takes place. In this way the surrounding soil is kept moist.
3. The technology is a conservation irrigation system, which saves between 50% and 70% water when compared to the conventional watering can irrigation system. Water is a scarce resource and thus its use must be optimized.
4. Clay pots reduce water use without reducing yields. Therefore it is a water saving technology which optimizes yields per unit water.
5. The clay pot irrigation system is a labour saving technology, both because of less labour required for irrigation and less labour required for weeding.
6. The fact that most rural women of Africa locally make clay pots, means that making clay pots for irrigation will potentially contribute towards creation of employment for them by means of a technology that they are proficient in.
7. The clay pot irrigation system greatly reduces fertilizer requirements, which greatly improves the economy of small-scale irrigation farming.

8. The clay pot irrigation system could be optimized by combining it with treadle pump technology.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

The study has established that Dambos, as ecosystems, are strategic resources worthy exploiting for food production to cope with hunger which manifests particularly during drought years. Two reasons account for this: Firstly, they remain wet for a prolonged period into the dry season and their water tables are shallow enough to enable growing of vegetables. Secondly, they are inherently rich in organic matter and nutrients since they act as depositional sinks for run-off from surrounding high ground.

Dambos as wetland ecosystems exhibit different forms and types. Scattered throughout Zambia, over 3.6 million hectares of land, they occur as sweet, intermediate and sour Dambos. This classification is largely based on soil acidity. This study has established that the use of modifiers to classify Dambos is plausible and takes into account the genesis, origin, land use, physical and chemical characteristics, vegetational and hydrological aspects. These considerations accord with the professional inclination that ecologists, hydrologists, eco-tourists, agriculturalists and socio-economists have in defining Dambos.

The study has further concluded that Dambos are key resource areas that small-scale farmers have utilized for several decades on a sustainable basis. Given the frequent droughts that have characterized southern Africa and the associated dismal performance of rainfed crops, a mounting pressure on the use of Dambos has been evident throughout their places of occurrence because of their water storage and supplying potential which can support dry season cropping. In view of this, the study recommends options for wise land use on a sustainable basis.

The rain season affects different Dambos in different ways with frequent floods precluding cropping in some unless coping strategies are adopted by farmers whilst others assume optimal soil moisture conditions to allow for crop cultivation in them. These differences manifest depending on whether the Dambo is morphologically an upland, lowland or hanging Dambo. Rainfall distribution and intensity are major factors identified as recharging mechanisms. Vegetation changes in Dambo watershed influences recharge when evapotranspiration declines due to tree removal, the loss or shedding of leaves or replacement of trees by shallow rooted annual vegetable crops which transpire less than deep rooted trees in the Dambo watershed. Flooding intensity in Dambos during the rain season is linked to intense upland cultivation where soils are well drained. Extreme drought years are associated with receding water tables which force farmers to deepen wells to access the water.

Major limitations of lifting and transporting this water to areas where vegetables are grown within the Dambo suppress production because farmers traditionally use a small bucket tied to a rope to draw water and walk to a vegetable plot to irrigate limited pieces of land.

Due to the advent of the treadle pump technology, adapted according to farmer preference by this study and introduced in the pilot areas, net positive results are noticeable. The farmers have brand-named the treadle pump as the **"Chova pump"** which means to **"boost productivity and income"** and/or to **"pedal"** the device for it to operate. The manual foot operated pump has a copious discharge of between 1.5 l/s and 2.0 l/s which allows a farmer to irrigate larger areas than before and apply adequate amounts of water which give a long opportunity net-time as compared to deficit amounts applied using conventional buckets/watering cans wherein an everyday irrigation schedule is mandatory in order to cope with crop water requirements. The new technology is sustainable as it does not over pump and allows for any excess water to percolate into the soil and recycle back to the water table. In this way the Dambo is not at risk of drying up due to injudicious or unscrupulous means of water abstraction.

The pump has brought about some socio-economic, cultural and farming systems impacts on the community. Despite marketing problems which take place from time to time due to glut and poor infra-structural arrangements, farmers have been able to market their surplus produce resulting from increased yields due to the use of treadle pumps for irrigation. The study has documented cropping calendars developed by farmers to cope with flooding and marketing problems. They plant crops at certain times of the year to escape flooding or to coincide with existing local markets for the produce.

The introduction of the pump has attracted men to participate in irrigating vegetables - a role which was previously exclusively left to women and children who used buckets and watering cans. Due to this development, women are now able to do other chores whilst their husbands are operating the treadle pump to water the crops. Farmers are now able to irrigate larger areas (0.25 ha) per working day within 3-4 hours using the pump than the 0.10 ha in eight hours per day using watering cans and buckets.

The ease with which farmers are able to irrigate has resulted into extended dry season cropping and a change in their farming system. They now work throughout the year rather than have the now abandoned traditional ceremonies in the dry season as they would now be pre-occupied with irrigated vegetable cultivation. The associated positive impacts the pump has had in a short period of piloting has induced an adoption rate at an average of 800 pumps bought by farmers per year. To date there are about 2,500 pumps in use by farmers. This means that there are about 15,000 direct beneficiaries of the technology given that each farm family comprises six members.

Together with the treadle pump technology, the study has further introduced and disseminated to smallholder farmers, the clay pot sub-surface irrigation which saves on water by between 50% and 70% compared to the conventional irrigation systems. The system is very efficient in water utilization by crops. The technology is sustainable as it is home-made and involves rural women. This contributes to rural employment creation among women who make the pots. The system is also appropriate for fruit trees which do well in the upper rassland zone where sandy soils are characteristic. With this irrigation system, labour savings are envisaged as there are long intervals between replenishing the water in the pots. Potential yields are also increased or maintained. Treadle pumps can be used to refill the pots by drawing water from the lower/central Dambo zones and reticulating it to higher lying areas of the Dambo where fruit trees easily adapt. The system supplies water to the crops as and when needed without undue over-irrigation and deep percolation.

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APPENDICES

APPENDIX I: Soil Profile Descriptions

(A). Mugabi Dambo (Central Zone)

(A). Mugabi Dambo (Central Zone)

Date:	16/08/1998
Location:	At the centre of the Dambo near the source of Lutembwe River
Land Use:	Vegetable gardens
Depth to Ground water table:	1.5 m
Drainage:	Very poorly drained
Parent material:	Granite
Slope:	0-0.5 % (very flat)
Vegetation:	Hyparhenia grass surrounded by Miombo woodland trees.

Soil profile characteristics

0-30 cm	Presence of dry organic matter in the top layer. Dark greyish colour (10YR3/1) when dry and black (10YR2/1) when moist. Small roots present; slightly soapy feel. Sandy loam.
30-60 cm	Grey colour (10YR5/1) when dry and very dark greyish brown colur when moist (10YR3/2). Absence of roots. Cracks ramifying throughout the horizon. Dry Sandy Clay Loam soil.
60-100 cm	Dark yellow brownish colour when moist (10YR4/6) with red mottles indicating periodic changes of water table. Very sticky when wet; hard when dry; few roots but some up to 3mm in diameter.

(B) NOOLE Dambo (Central zone)

Date:	20/06/1998
Soil Name:	Eutric vertisol (FAO)
	Paleustollic pellusterts (USDA)
Location:	200m West of Mweemba farm at 1300m aMSL.
Slope :	1 - 4%
Land Use:	Natural grazing land
Parent material:	Alluvial
Depth to Ground water table:	2.14m (reading from piezometer)
Erosion Evidence:	None
Soil drainage class:	Very poorly drained.

Brief Description of Profile:

Very poorly drained,silt clay top texture and control section being clay texture. The colours being uniform, at top when moist (10YR3/1) very dark gray and the bottom colour (10YR4/1) dark gray.

Soil profile characteristics

0-35 cm (Ap)	Very dark gray (10YR3/1) moist and dark gray (10YR3/1) dry, clay; strong fine to medium columns; very stick, very plastic, very firm moist, very hard dry; very fine pores, common fine, few medium and coarse roots, diffuse wavy boundary. PH=5. Cracks extending upwards to top of horizon.-35 cm (Ap); Very dark gray (10YR3/1) moist and dark gray (10YR3/1) dry, clay; strong fine to medium columns; very stick, very plastic, very firm moist, very hard dry; very

	fine pores, common fine, few medium and coarse roots, diffuse wavy boundary. PH=5. Cracks extending upwards to top of horizon.-35 cm (Ap); Very dark gray (10YR3/1) moist and dark gray (10YR3/1) dry, clay; strong fine to medium columns; very stick, very plastic, very firm moist, very hard dry; very fine pores, common fine, few medium and coarse roots, diffuse wavy boundary. PH=5. Cracks extending upwards to top of horizon.
35-100+cm	Dark gray(10YR4/1)when moist and gray (10YR5/1)when dry. Extremely firm moist. Clay; strong medium prisms, very sticky, very plastic. Common faint mottles observed throughout the profile. 1cm wide cracks observed running vertically.

(C) (Fikolwa Seepage Zone)

Date : 21/08/1998
Drainage: moderately well drained
Land Use: Cultivated vegetables and grass covered in most parts of Dambo
Slope: 0-<1%
Micro-relief: Flat

Brief Description:

Evidence of four sub-divisions in the profile with oxidation and reduction in the centre of the profile due to the existence of a high or perched water table due to gleying as one goes down the profile.

Soil profile characteristics

0 - 20 cm	Dark brown sandy loam soil (7.5YR3/2) moist and grayish (7.5YR6/2) dry. Weak medium subangular block. Organic matter with lots of roots. Non sticky, non plastic, friable.
20 - 40+ cm	Greyish pinkish (7.5YR4/2) moist sandy loam with cracks up to 45 cm and. Presence of termite holes observed.)
40 - 80cm	Sandy loam soil gray whitish brown colour (10YR5/2) moist and pinkish gray (7.5YR7/2) dry. Coarse sand massive, non-sticky, non-plastic, loose moist, hard dry with common very fine roots.
80-100+ cm	Dark greyish colour(7.5YR7/3). Coarse sand, Presence of mottles and laterite/stones. Evidence of water table at 1.2 - 1.7m

APPENDIX II: Socio-Economics Baseline Study Questionnaire

Village Profile

1. When was the village established?
2. What ethnic groups exist in the village?
3. Population/households
4. Means for the village livelihood
5. Existing infra-structure:
    - roads
    - schools
    - clinic
    - market
    - storage sheds

Socio-Economis

1. What is the Dambo name you are using?
2. Number of households utilizing Dambos?
3. When did you start growing crops in Dambos?
4. How have been watering your crops?
5. What is the size of your Dambo garden?
6. What is the total land area of the Dambo under utilization?
7. How have people utilized Dambo?
    - past uses.
    - present uses.
8. When was it used for crop production?
9. From whom was the Dambo technology learnt?
10. What problems do you face in utilizing the Dambo?

11. How do you overcome some of the problems?
12. When do you carry out various operations in the Dambo?
13. How do those activities interfer with your upland activities?
14. What type of individuals utilize Dambos?
15. How many of those people are women?
16. What roles do men and women play in Dambo garden operations?
17. Who sells Dambo produce?
18. How do you use income raised from Dambo produce?
19. Who has control over the raised income?
20. Who keeps the money raised from Dambo produce?
21. What is the availabilty of food from Dambos over a year's season?

Dambo Access

1. Who has power of ownership of a Dambo garden in a household?
2. Who gives land in a Dambo? What is the process?
3. Are there any taboos or traditions related to Dambos?
4. What are the trends in Dambo use?
5. Are Dambo activities compatible with each other?

Agronomic Practices

1. Outline the main crops grown in Dambos
2. At what time of the year is the Dambo utlized most and why?
3. What are the existing cultural practices?
    - land prepartion
    - planting
    - irrigating
    - weeding

- fertilizing
- harvesting
- crop rotation

4. What methods are used to improve soil fertility?
5. What problems are associated with each crop listed?
    - water requirements
    - pests and diseases
    - nutrient deficiencies
    - yield
    - labour

6. Do you own and use a water lifting device?
7. How do you compare it with using conventional ways of irrigating?

Crop Utilization

1. How is the produce utilized?
2. Do farmers preserve any of the crops grown? if yes - how?
3. How has the Dambo contributed to the availability of food in the household?

Dambo Use For Livestock

1. What animals are used in the Dambo for grazing?
    - domesticated
    - wild
2. Are there any constraints in Dambo use for livestock?
3. Do you manage Dambos for the following;
    - fodder production?

- rotational grazing?

Marketing

1. How do you market your produce?
2. Are there any marketing problems?
3. Where is the produce from Dambos sold?
4. What are the distances to markets?
5. What are the prices like over the season?
6. Do prices fluctuate? if so what are the causes of this fluctuation?
7. What are the constraints/problems encountered in sale of produce?

Quality Of Dambos?

1. What are the soil types in Dambos?
2. What slopes obtain and is there any erosion?
3. Vegatation type found and its usefulness
4. Water holding capacities of soils?
5. What do farmers use to improve soil fertility
    - crop residue?
    - animal manure?
    - chemical fertilizer?
6. Are there any signs of deforestation in surrounding catchment?