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Overview of Water and Soil Nutrient Management under Smallholder Rain-fed Agriculture in East Africa

Bancy Mbura Mati

International Water Management Institute

FUTURE HARVEST
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Contents

Acronyms relevant to all the countries

ACT	African Conservation Tillage Network
ASAL	Arid and Semi-Arid Lands
AU	African Union
CBO	Community Based Organization
CCD	Conventions to Combat Desertification
COMESA	Common Market for Eastern and Southern Africa
DAP	Diammonium Phosphate
DDB	Double Dug Beds
DPT	District Planning Teams
EAC	East African Community
ECA	Economic Commission for Africa
EPM	Ecological Pest Management
FAO	Food and Agriculture Organization
FEW	Frontline Extension Worker
FI	Farmer Innovator
GDP	Gross Domestic Product
GFAR	Global Forum on Agricultural Research
GO	Government Organization
ICRAF	International Council for Research in Agroforestry
IDS	Institute of Development Studies (of the UK)
IFAD	International Fund for Agricultural Development
IFOAM	International Federation for the Organic Agriculture Movement
IFPRI	International Food Policy Research Institute
IGAD	Inter-Governmental Authority on Development
IIRR	Institute of International Research and Reconstruction
IPM	Integrated Pest Management
ITK	Indigenous Technology Knowledge
IWMI	International Water Management Institute
LEISA	Low External Input Sustainable Agriculture
MENR	Ministry of Environment and Natural Resources
MoA	Ministry of Agriculture
NARS	National Agricultural Research Stations
NEP	National Extension Program
NGO	Non-Governmental Organization
NRM	Natural Resource Management
PFI	Promoting Farmer Innovation
PRA	Participatory Rural Appraisal
PRSP	Poverty Reduction Strategy Paper
PTD	Participatory Technology Development
RWH	Rainwater Harvesting

SCC	Soil Conservation Committees
SEARNET	Southern and Eastern Africa Rainwater Network
SIDA	Swedish International Development Agency
SIWI	Stockholm International Water Institute
SPAAR	Special Program for African Agricultural Research
SSA	Sub-Saharan Africa
SWC	Soil and Water Conservation
SWCP	Soil and Water Conservation Project
SWMNet	Soil and Water Management Network
T&V	Training and Visits
UN	United Nations
UNDP	United Nations Development Program
WNCTs	Water and Nutrient Conservation Technologies
WOCAT	World Overview of Conservation Approaches and Technologies

Acronyms relevant to Ethiopia

AAEO	Assistant Agricultural Extension Officer
ARDU	Arssi Regional Development Unit
CADU	Chilalo Agricultural Development Unit
CRDA	Christian Relief and Development Association
MPP	Minimum Package Program
NVCC	National Villagization Coordination Committee
PA	Peasant Association
PADEP	Peasant Agricultural Development Program
PADETES	Participatory Demonstration and Training Extension System
PRUP	Participatory Resource Use Planning
SG2000	Sasakawa Global 2000 Project
WADU	Wallamo Agricultural Development Unit

Acronyms relevant to Kenya

MoA&RD	Ministry of Agriculture and Rural Development
AFC	Agricultural Finance Corporation
ALIN	Arid Lands Information Network
ATIRI	Agricultural Technology and Information Response Initiative
FFS	Farmer Field Schools
FSR	Farming Systems Research
HPI	Heifer Project International
IPPM	Integrated Production and Pest Management
ITDG	Intermediate Technology Development Group
KARI	Kenya Agricultural Research Institute

KEFRI	Kenya Forestry Research Institute
KENDAT	Kenya Draught Animal Technology
KIOF	Kenya Institute of Organic Farming
KWFT	Kenya Women Finance Trust
LLP	Local Level Planning
MDFP	Meru Dryland Farming Project
NALEP	National Agricultural and Livestock Extension Project
NSWCP	National Soil and Water Conservation Program
SFRRP	Soil Fertility Recapitalisation and Replenishment Project

Acronyms relevant to Tanzania

ARI	Agricultural Research Institute
CTP	Cashew Training Program
DONET	Dodoma Environmental Network
HADO	Hifadhi Ardhi Dodoma
HIMA	Hifadhi Mazingira
ISWCP	Indigenous Soil and Water Conservation Program
LAMP	Land Management Program
MVIWATA	Mtandao wa Vikundi vya Wakulima Tanzania
REDESA	Relief and Development Services Association
SCAPA	Soil Conservation and Agroforestry Project-Arusha
SDPMA	Smallholder Development Project for Marginal Areas
SUA	Sokoine University of Agriculture
TIPDO	Traditional Irrigation Development Organization
VDC	Village Development Councils

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Note: All the figures in this paper have been drawn by Munene M. Mati (from sketches and photos).

Foreword

The work that lies behind this Working Paper began, for Professor Mati, long before she began working with IWMI. But for IWMI, it also has a history of several years. During the years 2000-2001, as we built up our program and staff in Africa, we spent quite some time trying to identify what should be our main priorities in sub-Saharan Africa. By 2002 we realized that one very important focus for IWMI's work ought to be on water and land management in "rain-fed" as well as "irrigated" agriculture; we called our incipient effort "intensifying rain-fed agriculture," and focused on such topics as rainwater harvesting, small individualized technologies such as bucket and drum drip kits and pedal pumps, and low-cost water storage. As part of our effort to understand what is already happening in this arena, we asked Professor Mati to work with us on this topic and among other things to provide an overview of experiences in East Africa based on her on-going and past experiences.

The first draft of this paper was produced in 2003. She continued to work on it, adding examples, illustrations, data from more recent experiences, and for the final version, added a section on participatory approaches to implementation and scaling up. She has patiently answered questions from nonspecialists like me, and worked hard to finalize this document for wider dissemination.

I am sure that many people will find this overview a useful guide and menu. It is aimed at government officials, NGOs, and donors who are supporting the implementation of improved low-cost water and land management practices by and with poor farmers. I want, therefore, to thank Professor Mati for her work. I share Professor Mati's belief that helping farmers adapt and make good use of better but low-cost water and land management practices and technologies can have a high impact on poverty and food security in Africa.

As will be seen from her acknowledgments, many people have participated in various ways to make this Working Paper a reality. I do want to provide a special acknowledgment to the International Program for Technology and Research in Irrigation and Drainage (IPTRID). The finalization and publication of this Working Paper has been made possible by the IWMI-IPTRID Partnership (LOA PR No. 28920), which is supported by the Government of the Netherlands.

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INTRODUCTION

Background

Agriculture is the most important economic activity in sub-Saharan Africa (SSA) supporting over 67 percent of the population, but 60 percent of these depends on rain-based rural economies, generating in the range of 30-40 percent of the countries' GDP (World Bank 1997). However, rainfall is poorly distributed, ranging from 1,430 mm per annum in central African countries to about 71 mm in arid countries (ECA 2003). Moreover, food insecurity and poverty are the greatest threats to sustainable development in the region. Over 200 million people do not have sufficient food and this is 30 million more than a decade ago (and nearly 60 million more than 20 years ago). About one-third of the people of SSA are malnourished, with more than 60 percent of these in East Africa; in West Africa the number of malnourished people has fallen dramatically (InterAcademy Council 2004:9). East Africa is a geographic region covering 10 countries, that include Kenya, Tanzania and Uganda (these three form the East African Community), plus Djibouti, Ethiopia, Eritrea, Somalia, Rwanda, Burundi and Sudan (figure 1.1). Sometimes the region is described as the "Greater Horn of Africa" (IGAD 2001). East Africa is occupied by some of the poorest communities in the world and over 50 percent of the population lives below the poverty line. The per capita income in generally less than US$300 per annum (Africa's average is US $500).

With the exception of Uganda, Rwanda and Burundi, the region is characterized by semi-humid to semi-arid climate, where 73 percent of the land is classified as dryland. Drought is a common phenomenon, affecting about 100 percent of the land in Somalia, Eritrea and Djibouti, and 61-87 percent of the land in Ethiopia, Kenya and Sudan (Sanders and McMillan 2001). Annual rainfall in East Africa range from about 150 mm in the arid and semi-arid areas to over 2,000 mm in the wet, mostly highland regions. This amount of rainfall in itself should be capable of ensuring sustainable agricultural production. However, the real situation is that agricultural production is below potential land capabilities in nearly all the countries, and crop failures are a common occurrence. The low productivity is usually associated with prolonged and recurrent drought and dry spells. Yet only about 5 percent of the irrigation potential has been exploited. Moreover, more than two-thirds of the irrigation potential is located in humid regions. There is, therefore, an urgent need to make rain-fed agriculture more productive.

Recent studies (Reij and Waters-Bayer 2001; Bittar 2001; Abbay et al. 2000, Critchley et al. 1999; Hatibu and Mahoo 2000) have shown the emergence of success cases of rain-fed agriculture in East Africa, which are transforming the lives of many poor farmers. Innovative and indigenous technologies have been applied to achieve improved yields. These have involved a wide diversity of interventions, ranging from integrated soil fertility management (Ndakidemi et al. 1999), soil and water conservation, rainwater and runoff harvesting systems, integrated pest management, tillage and soil management systems, improved seeds, and innovative agronomic practices. In addition, developing participatory methodologies in research, extension and training have enabled faster out-scaling of successful interventions. Appropriate extension tools have been developed that allow farmer participation in research and development. However, these success cases are few and far between, and there is a need to have continuous collation of information, building on knowledge gained from the successful practices, so as to reach as many farmers as possible, and thereby enhance agricultural development in the region. This paper reviews some of the more commonly adopted water and soil nutrient management technologies and approaches in East Africa, targeting Ethiopia, Kenya and Tanzania.

Figure 1.1. Africa—showing East Africa, Kenya, Ethiopia and Tanzania.

Ethiopia

General Background

Ethiopia lies between longitudes 33°E and 55°E and latitudes 3.5°N and 15°N, covering a land area of 1.13 million km² (Appiah and Gates Jr. 1999). The country is bounded by Eritrea, Djibouti, Somalia, Kenya and the Sudan. The relief is dominated by Ethiopian highlands and thus the climate is quite variable across the country. The tropical zone receives less than 510 mm rain per annum, while the sub-tropical zone, which includes most of the highlands, receives 510 to 1,530 mm of rain annually. In general, the main rainy season occurs between mid-June and September, followed by a dry season that may be interrupted by the short-rains season in February-March. Mean annual temperatures range from about 27° C in the tropical zones to about 22°C in the cooler highlands. Population is estimated to be 70 million people, with an annual population growth rate of nearly 3 percent. Per capita income in 2002 was US$90 per year (World Bank 2004; Awulachew et al. 2005).

The physical features of Ethiopia include large areas of flat land and gently rolling hilly areas as well as steep and ragged hills and valleys. Altitudes range from slightly below sea level to more than 4,000 m above sea level, and slopes can be as high as 60 percent in the highlands, making large areas more prone to erosion. The Ethiopian highlands represent one of the most productive parts of the country, but have suffered from extensive resource degradation. Since the 1970s, attempts to reverse degradation through soil conservation programs have been implemented. Although there have been successes, more often, the results have been disappointing (Holden and Shiferaw 1999).

The drylands of Ethiopia comprise about 70 percent of the total landmass and 45 percent of the arable land, including arid, dry semi-arid, moist semi-arid and parts of the sub-moist zone. However, these areas contribute only 10 percent of the total crop production. About half of the arable land is in the arid and semi-arid regions, and most rural people living in such areas depend on small-scale dryland agriculture. The drylands are characterized by a severely fragile natural resource base. Soils are often coarse-textured, sandy, and inherently low in organic matter and water-holding capacity, thereby making them easily susceptible to both wind and water erosion. As a result, crops can suffer from moisture stress and drought even during normal rainfall seasons. Farm productivity has declined substantially and farmers have found themselves sliding into poverty (Kidane 1999).

Agriculture and Food Production in Ethiopia

Settled agriculture in Ethiopia has a long history dating back to antiquity, and is the mainstay of Ethiopian economy. It contributes 57 percent of the GDP (Holden and Shiferaw 1999). Agriculture employs about 85 percent of the population in Ethiopia and accounts for 90 percent of the national export earnings. In the 1990s, the economic growth rate increased to 5 percent, as compared to 1.6 percent in the 1980s. Major changes in economic policy since 1992 have provided a conducive environment for development. These include reducing the role of government, encouraging privatization, liberalizing markets and rationalizing exchange rate policies (FAO/WFP 2000). Between 1979/1980 and 1993/1994, food production (of crop and animal origin) grew annually by a mere 0.5 percent and food grain production by 0.44 percent. This is equivalent to an annual per capita domestic food availability decline of 2.55 and 2.7 percent, respectively.

Much of Ethiopia, especially the mountain valleys, has sufficient rainfall and good soil for crop production. However, population pressures are so extreme that farmlands are under continuous cultivation. Cereals occupy 82 percent of the cultivated areas, while pulses occupy 12 percent. The main crops are teff, maize, sorghum and barley. In addition, there are about 13 million cattle, 12 million sheep, 10 million goats, 4.4 million equine and 1 million camels (Tegegne 2000). Generally, Shoa, Arssi and Gonder are the main food producing areas. Problematic areas include Wollo, Herarghe, Tigray, Bale, Sidano and Ganu Gofa (Gribnau 1993). Agriculture in Ethiopia is dominated by approximately 7 million small-scale and resource-poor farmers, with average landholdings of about 1.5 ha in size. There are four major farming systems in Ethiopia (UNDP/ECA 1998):

- Cereal – oil – pulse – livestock farming system is found in the central highlands of Ethiopia, in the northern highlands of Tigray and also in the Amhara National Regional State. This system has intense potential and is well developed, and in addition, the population is hard working. The soil being enriched with rich alluvial, and if water is developed, production could be tripled or quadrupled.

- Cereal – livestock – hoe culture, where agricultural production does not have a long tradition, is in the western and southern regions of Ethiopia and the Southern National Regional State as well as in Gambella and Benshargul – Gumuz.

- Pastoral farming – is in all regional states, but dominant in Afar, Somali and Benshangul-Gumuz National Regional States. The area is vulnerable to drought, and there is a lack of knowledge about modern technologies. There is also a scarcity of trained manpower in the area.

- Coffee – maize – livestock – root crop enset farming system is represented by Oromiya and Southern Nationals, Nationalist and Peoples' Regional States. This system is in major cash-crop areas with enset and maize being the major food crops. Enset, a banana-like plant typical to Ethiopia and is usually grown in home gardens.

Among the reasons for poor agricultural development, there have been constraints associated with strategies such as (i) development and conservation of hillsides and communal lands, (ii) "food for work" based development, (iii) exclusion of farmers in the day-to-day development and conservation initiatives, (iv) disregard of indigenous development and conservation skills, (v) rural land use and tenure policies, (vi) lack of knowledge about soil erosion, and (vii) institutional set up and continuity (Bekele-Tesemma 2001). These constraints have contributed to failures in development projects. The failures can further be attributed to biophysical and sociopolitical factors. The use of modem agricultural inputs (fertilizer, selected seeds, agro-chemicals, and improved farm implements) is limited. Moreover, environmental degradation is expanding at an alarming rate and this trend is exacerbated by drought, which is considered as a major destructive process. Rapid human and animal population growth, coupled with limited arable and grazing land, has reduced the carrying capacity of the environment (Ejigu 1999).

Other aspects have included changes in extension approaches, from the top – down approaches to conservation initiated after the 1973/1974 famine and the 1975 land reform, and establishment of the Peasant Associations (PAs), which were instrumental in mobilizing labor and assignment of local responsibilities. Since the 1980s, food-for-work programs have mobilized 35 million person-days of labor for conservation in the highlands. However, the success rates were limited. For instance, of the trees planted, the survival rate was 60 to 70 percent. In addition, uniform soil conservation structures were constructed across different regions, which were later dismantled on 53 percent of farms and partly removed on 31 percent when coercion ceased (Holden and Shiferaw 1999). Moreover, prospects for agricultural development in dry areas are largely misunderstood. These areas are commonly called "low potential" rather than "low rainfall" areas. Besides livestock, arid and semi-arid lands (ASALs) are the sources of millets, sorghum, cotton, cowpeas, dolichos beans, pigeon peas, oranges, mangoes, grapes and passion fruits. Appropriate technology for these areas has been lacking —paradoxically, the future of the expansion of Ethiopia's food production is in these areas (Georgis 2002). In the Eastern Shoa Region of Ethiopia, the most common water harvesting methods include: contour stone bunds, trapezoidal bunds, flood water diversion/spate irrigation (forced flood diversions), flood water farming systems (riverbed/bank utilization-no diversion), contour ridges/contour furrows and semi-circular bunds (Natea 2002).

Kenya

General Background

Kenya lies between longitudes 34°E and 42°E and latitudes 4.7°S and 5°N, covering an area of 582,646 km². Kenya shares boundaries with Tanzania, Uganda, Ethiopia, Sudan, Somalia and the Indian Ocean. The country has a diverse topography, ranging from sea level to the high altitude peaks of Mount (Mt.) Kenya at 5,199 meters above sea level, and other highlands. Climate is influenced by altitude, and annual rainfall amounts vary much across the country, from less than 200 mm in the arid north to over 2,000 mm on the upper slopes of Mt. Kenya (Sombroek et al. 1980). About 80 percent of the land in Kenya is classified as ASAL receiving 200 to 750 mm of rainfall per year. The ASALs are hot and dry, where rainfall is erratic and unreliable, with seasonal distribution that does not allow good crop harvests. Thus, ASALs are classified as unsuitable for crop production (Jaetzold and Schmidt 1983). Kenya has a population of 28.7 million people, as per the 1999 population census (Republic of Kenya 1999). The annual population growth rate is 3 percent. Per capita income in 2000 was US$350 per year (Republic of Kenya 2000; World Bank 2002).

Agriculture and Food Production in Kenya

Agriculture is the major economic sector in Kenya, and is the main source of income for some 80 percent of the population, of which 19 percent is in wage employment. It accounts for 52 percent of the national GDP, of which 25 percent is directly and 27 percent is indirectly through linkages with manufacturing, distribution and other service-related sectors. Agriculture accounts for some 40 percent of the total export earnings, 45 percent of the government revenue and 75 percent of the industrial raw materials (Republic of Kenya 2000; MoA&RD 2002). There are about 3 million smallholder farm-families in Kenya, of which 80 percent have less than 2 ha of cropland. Smallholders are responsible for 70 percent of the maize production, 65 percent of the coffee, over 50 percent of the tea, over 70 percent of beef and over 80 percent of milk and other crops (Republic of Kenya 1995). Despite this, some 2 million people in Kenya are considered to be chronically food insecure and the number increases to 5 million in the event of drought, even during seasonal droughts. According to the World Bank (2002), approximately 42 percent of Kenyans live below the poverty line. Furthermore, only about 20 percent of the land area in Kenya is suitable for rain-fed agriculture.

Agricultural production and real expenditures in agriculture in Kenya declined at 1 percent throughout the 1990s, while contribution of agriculture to the GDP was negative (MoA&RD 2000). However, the contribution of smallholder farmers was growing. Similarly, there was a decline in public support for research and extension, and as a result, maize yield increases fell to 0.3 percent in the 1985-1991 period (World Bank 1995; Hassan and Karanja 1997). However, the agricultural sector has been recovering in recent years and in 2003, the sector grew by 1.5 percent (Republic of Kenya 2004). Over the years, population pressure and lack of growth in other sectors have caused increasing pressure on natural resources, resulting in declining soil fertility, productivity and general environmental degradation. Furthermore, the situation has been exacerbated by a weak capital base, over-taxation of farm inputs, disorganized marketing system, drought, insecurity in the rangeland areas, poor extension services, inadequate exploitation of some water resources and poor functionality of supporting agricultural infrastructure such as cooperative societies. These conditions have raised concerns in Kenya and among her development partners, and led to the formulation of reforms as spelt out in the Poverty Reduction Strategy Paper (Republic of Kenya 2001).

The Poverty Reduction Strategy Paper (PRSP) for the period 2001-2004 for Kenya outlines measures necessary for poverty reduction, food security and economic growth (Republic of Kenya 2001). Agriculture and rural development, in general, were identified as the key sectors to tackle poverty reduction. Within the sector, priorities were ranked as: 1) crop development, rural water; 2) livestock development; and 3) food security, lands and settlement management and fisheries (MoA&RD 2002). At the national level, strategies and approaches have been proposed, and some are being implemented in the current development plan. These include the following (MoA&RD 2000; 2002):

- Documentation of successful technologies and approaches that have significantly contributed to food security;
- Building partnerships for agricultural and food security initiatives;
- Capacity building and sustainability;
- Undertake deliberate programs to expose farmers to technologies and information;
- Wider involvement of stakeholders;
- Develop strong farmer-extension-research linkages;
- Provision of an enabling environment for private sector participation in extension;
- Support value adding to agricultural produce and products;
- Address gender equity; and
- Develop modalities for up-scaling successful projects.

Tanzania

General Background

The United Republic of Tanzania is made up of mainland Tanganyika and the islands of Zanzibar and Pemba. The country covers a total land area of 945,087 km², of which Zanzibar and Pemba occupy about 1,658 km² and 984 km², respectively. Tanzania lies between longitudes 30°E and 40°E and latitudes 1°S and 12°S. It is bounded by Kenya, Uganda, Rwanda, Burundi, Democratic Republic of Congo, Zambia, Malawi, Mozambique and the Indian Ocean. The relief of mainland Tanzania is, generally, flat and low along the coast, but a plateau of average height of 1,200 m constitutes the greater part of the country. Isolated mountain ranges rise in the northeast and southwest. The snow-peaked Mt. Kilimanjaro at 5,895 meters above sea level, which is the highest mountain in Africa, is located near the northeast border with Kenya. Other highlands include Mt. Meru (4,556 m), Pare Mts, Uluguru Mts and the southern highlands of Mbinga and Njombe. Along the coast are the narrow, low-lying islands of Zanzibar, Pemba and Mafia. More than 53,000 km² is covered by inland lakes, such as Lake Victoria in the north, and the Rift Valley lakes, Tanganyika and Nyasa (Appiah and Gates Jr. 1999; URT 1994). The population of Tanzania is about 34 million people, with an annual growth rate of 2.3 percent. The per capita income in 2000 was US$270 per year, and the proportion of people living below the poverty line was 42 percent (World Bank 2002).

Compared to Kenya and Ethiopia, Tanzania has a moderate climate. The climate is warm and tropical on the mainland coastal strip along the Indian Ocean, with temperatures averaging 27°C and annual rainfall varying from 750 to 1,400 mm. The inland plateau is hot and dry, with annual rainfall averaging as low as 500 mm. On the islands, where annual mean temperatures are in the range of 29° C, the excessive heat is tempered by the sea breeze throughout the year (Appiah and Gates Jr. 1999). Tanzania is a mineral-rich country, producing small amounts of diamonds, gemstones, gold, salt phosphate, coal, gypsum and also kaolin and tin. There are reserves of nickel, soda ash, iron ore, uranium and natural gas. However, the mineral potential of Tanzania has not been fully exploited.

Agriculture and Food Production in Tanzania

Agriculture is Tanzania's most important economic sector, providing food, income, fuel, shelter and employment to the rural and urban population. It accounts for 70 percent of foreign exchange and 80 percent of employment. Statistics show that 40 million ha of Tanzanian land is suitable for agricultural production, but only 6.3 million ha are under cultivation (URT 1997). One million ha have the potential for irrigation, but only 150,000 ha are actually under irrigation. This is indicative of the reality of smallholder agriculture and the constrained technological base. Though most of the farming is for subsistence, growing food crops like maize, rice, beans, citrus, vegetables, root crops, and cash crops form an important economic component. The main cash crops include coffee, tea, cotton, sisal, tobacco, coconut, sugar, groundnuts and cashew nuts. Cloves are an important cash crop in the islands of Pemba and Zanzibar.

Most crops and livestock are produced by small-scale farmers who use few capital inputs. As a result, soil fertility is declining in most farming systems of the country. Due to liberalization of the economy, more produce is being marketed and processed thereby, accelerating depletion of natural soil fertility. These two conflicting trends reflect the major challenge for agricultural research, extension and development organizations (Ndakidemi et al. 1999). Some of the problems that have plagued agriculture in Tanzania include the formulation of blanket recommendations, which are too general to be applicable in the case of individual farmers, and the unavailability of chemical inputs in remote areas of the country. Since the liberalization of the Tanzanian economy in 1986, there have been policy changes that have contributed to renewed growth in the agricultural sector. The short-term measures have included liberalization of regional food trade, improvements in credit provision to farmers, reduction of excessive taxation of agricultural production and marketing by local authorities, and increased budgetary support for agriculture (World Bank 2000). Other macroeconomic reforms have included increased investment in research and extension, improvements in rural infrastructure and enhanced privatization of service provision.

SOIL AND WATER CONSERVATION TECHNOLOGIES

Water and soil nutrient management form a critical component of agricultural production. Water and nutrient conservation technologies are dictated by the need for soil conservation on usually very steep slopes while draining excess runoff safely, the need for water harvesting and conservation in the drier areas, the available technology, which is usually manual or draught animal, and labor. All three countries, Ethiopia, Kenya and Tanzania have a rich heritage of indigenous and innovative water and nutrient conservation technologies, including irrigation and water harvesting systems that date back centuries (McCall 1994; Reij et al. 1996; Wolde-Aregay 1996; Thomas 1997; Critchley at al. 1994; Mutunga et al. 2001; SIWI 2001).

The line between soil and water conservation (SWC) and rainwater harvesting (RWH) technologies for crop production is very thin. SWC can be described as activities that reduce water losses by runoff and evaporation, while maximizing in-soil moisture storage for crop production, but the same could be said of RWH. The two are differentiated by the fact that under soil and water conservation, rainwater is conserved *in-situ* wherever it falls, whereas under water harvesting, a deliberate effort is made to transfer runoff water from a "catchment" to the desired area or storage structure (Critchley and Siegert 1991). The important thing is that both systems complement each other, and under rain-fed agriculture in dry areas, both are necessary nearly all the time. Various interventions in SWC are implemented by farmers throughout East Africa, and they also form the foundation of many development projects with agriculture and land management on their agendas (Reij et al. 1996; Lundgren 1993; Hurni and Tato 1992; WOCAT 1997). Indigenous and innovative technologies in SWC, RWH and soil nutrient management abound in East Africa (Mulengera 1998; Reij and Waters-Bayer 2001; Hamilton 1997), some of which have proved easier to replicate, especially those that are applicable over diverse biophysical conditions and have low labor requirements.

In Ethiopia, the more common methods of SWC, RWH and nutrient management include: level contour bunds, grass strips, cutoff drains, hill terracing and graded bench terraces, while water harvesting is practiced in underground tanks, open pans and ponds, spate irrigation and in various tillage systems (Wolde-Aregay 1996; Hurni and Tato 1992). In Kenya, the more common ones include: terracing, vegetative barriers, conservation tillage, runoff harvesting and innovative technologies that trap and retain soil, improve its fertility or facilitate soil-moisture conservation and storage— these take different forms and techniques (Thomas 1997; Critchley at al. 1994; Mutunga et al. 2001). In Tanzania, the main interventions have included the tapping of runoff from roads, diversion of surface runoff from rocky areas, footpaths, conservation tillage, pitting systems, bunded basins, ridging, terracing and various types of runoff farming systems (McCall 1994; Reij et al. 1996; Zehnder et al. 1986; Hatibu and Mahoo 2000). They are described in the following section.

Terracing

Reducing slope steepness and/or length is also referred to as terracing. A terrace has been described (Critchley 2000) *"as a unit consisting of a relatively steeply faced structure across the slope (referred to as a riser, bank, dyke, ridge, wall or embankment), that supports above it a relatively flat terrace bed (which may be either flat, or sloping backwards or forwards and may slope laterally)."* Thomas (1997) concisely describes a terrace as "*a more or less change in slope profile with a reduction in gradient of the planted zone.*" Terracing by excavating ditches, construction of earth and some stone bunds, and vegetative barriers are normally defined as soil and water conservation (SWC) structures, and are primarily promoted to reduce soil erosion. On sloping lands, terracing is necessary for reducing overland flow rates thereby, contributing to water and nutrient conservation. Although terracing steep lands in East Africa has been an indigenous technology among some communities, new methods have been evolving over the years as the need to be innovative with ever-decreasing space for cultivation grows with the population, especially in the densely populated and erosion-prone highlands (Hurni 1993; Critchley 2000). In particular, from the 1970s, SIDA-supported soil conservation activities targeting high-potential steeplands of Ethiopia, Kenya and Tanzania (Lundgren and Taylor 1993; Wenner 1981; Thomas 1997), along with other programs and projects have generated not only tangible benefits to farmers, but also a large body of knowledge. Design of soil conservation structures was of necessity pegged to the 1-meter vertical interval in Ethiopia and 1.8 m in Kenya regardless of the slope steepness. This was done to avoid complicated calculations, so that farmers could lay out the terraces by themselves (Wolde-Aregay 1996; Thomas 1997). Some of the more common terracing technologies used by smallholder farmers include contour bunds, "fanya juu" terraces, bench terraces, stone lines and vegetative barriers.

Grass Strips and Vegetative Buffers

Grass strips are the least costly and least labor-demanding soil conservation structures. They combine characteristics of both biological and structural measures. Grass strips are a popular and easy way to terrace land, especially in areas with relatively good rainfall, where grass is used also as fodder. (Thomas 1997; Duveskog 2001). The grass is planted in dense strips, about 0.5 to 1 m wide, along the contour, at intervals equivalent to calculated terrace spacing. These lines create barriers that minimize soil erosion and runoff, through a filtering process. Silt builds up in front of the strip, and with time, benches are formed. The spacing of the strips depends on the slope of the land. On gentle sloping land, the strips are made with a wide spacing (20-30 m), while on steep land the spacing is about 10 to 15m. The grass needs to be trimmed regularly, to prevent spreading to the cropped area. The grass is cut and normally used as livestock fodder or as mulch. Many grass varieties are used, such as napier, guinea and guatemala grass. The main drawback with grass strips is that they harbor rodents and in dry areas, they may not survive the dry spells (Duveskog 2001). Grass strips have been widely used in Tanzania in the Kondoa area of Dodoma, also in Arusha, Iringa and Kilimanjaro regions (Christiansson et al. 1993; Critchley et al. 1999; Lameck [personal communication]; Thomas and Mati 1999). In Kenya, they are commonly found in the highlands of Central and Rift valleys where there is good rainfall. In Ethiopia, they have been adopted in the highland areas (Wolde-Aregay 1996). Sometimes, natural vegetative strips are left unploughed during land preparation leaving a living buffer strip, especially in dry areas where grass strips have a slim chance of survival (Wenner 1981).

Contour Bunds

Contour bunds are soil conservation structures that involve construction of an earthen bund by excavating a channel and creating a small ridge on the downhill side. The difference from earthen bunds is in the fact that contour bunds are used for draining excess runoff from steep cultivated slopes, while earthen bunds are used for runoff harvesting usually on relatively less steep lands. Thus contour bunds resemble narrow channel terraces, which in Kenya are referred to as "fanya chini" terraces. Contour bunds are used for prevention of flooding and are popular in the highland areas of Ethiopia, usually designed with a standard 1 m vertical interval. The construction of the bunds received ample support in the 1980s through the food-for-work projects implemented by the World Food Program. The result was a dramatic transformation of crop farmlands and hills into impressive terraced landscapes. However, no attempt was made to adapt the measures to local conditions and to some of the traditional conservation measures, instead of being improved upon, were totally ignored and replaced by the new ones (Wolde-Aregay 1996; Lundgren and Taylor 1993). In the high rainfall areas north of Shoa and Gojam, problems of waterlogging occur at times, but this problem can be avoided by making drainage ditches between terraces.

Trash Lines

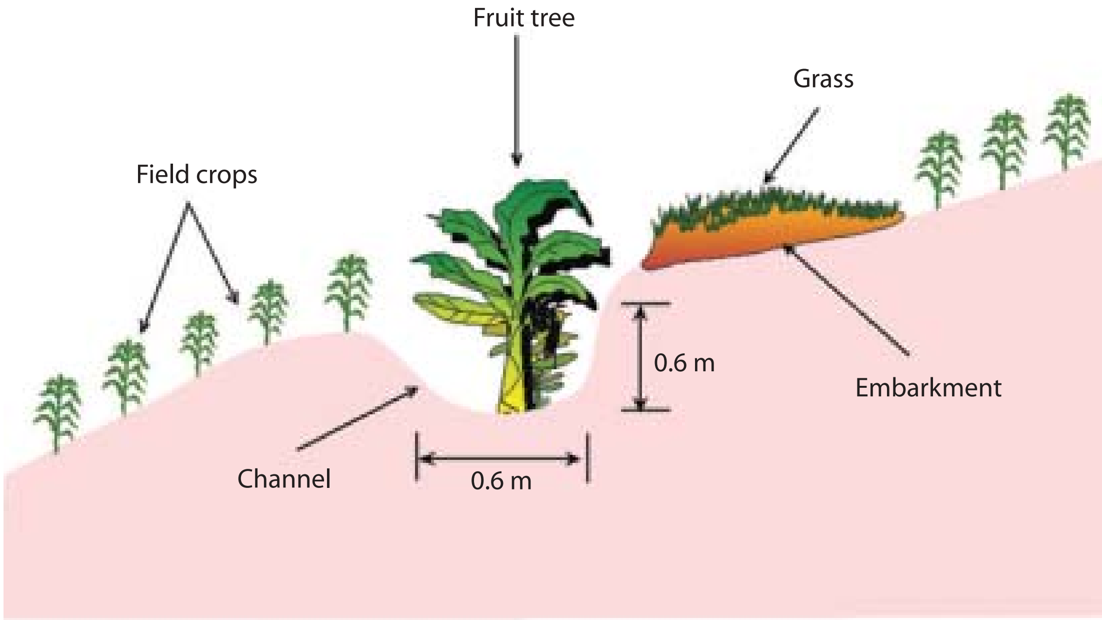
Trash lines involve arranging the previous season's crop residues or any other dead vegetative materials in lines across the slope to form organic buffer strips along the contour (Thomas 1997; Hudson 1981). Making trash lines is a traditional technique in many parts of Kenya (Maher 1937, 1938; Wenner 1981), though they are not as widely used as other bunding techniques. In the wetter areas where farm sizes are restricted, farmers prefer to feed crop residues to livestock, while in the dry areas trash lines are associated with termite infestation. Trash lines have the advantage of low labor requirement. They are to be found almost in all areas, but are particularly popular in semi-arid districts of Baringo, Tharaka, Mbeere and Mwingi.

Fanya Juu Terraces

"Fanya juu" terraces (figure 2.1), are made by digging a trench about 60 cm wide along the contour, and throwing the soil upslope to form an embankment, which has a significant effect in reducing slope-length, and hence soil erosion from steep croplands (Thomas and Biamah 1991). In some cases, enlarged embankments are made to allow ponding of harvested runoff and, therefore, the structure can be used in water harvesting systems having external catchments. The soil bund retains water and thereby, safeguards yields even during droughts. "Fanya juu" terraces are suitable on slopes with annual rainfall of 500-1,000 mm. Planting grass, trees and bushes along the terrace banks stabilizes the bunds, while contributing to productivity and biodiversity such as fodder, fuel and fruits. The bunds gradually become enlarged as soil is transported downwards and deposited upon them. Within a few years, a terrace is developed through natural processes of erosion and deposition (Thomas and Biamah 1991).

The success of the "fanya juu" terraces among smallholder farmers in the region has largely been due to its simplicity and easy replicability across a wide range of agro-climatic zones and slope gradients (Thomas 1997; Wenner 1981). The method was popularized in the sub-region by Sida's Regional Soil and Water Conservation Unit in the 1980s (Lungren and Taylor 1993, Assmo and Eriksson 1999). Tiffen et al. (1994) present evidence from Machakos District in Kenya suggesting that the adoption of "fanya juu" terraces played an important role in reducing land degradation over the period from 1930s -1990s when population increased more than fivefold. For instance, in a study of soil conservation methods in Kiambu District in Kenya, Mati (1984) found that "fanya juu" terraces accounted for over 50 percent of all soil conservation interventions. Results from studies have shown substantial increases in yield on land with "fanya juu" terraces compared to non-terraced land (Ngigi 2003). Studies in Kangundo, Machakos District, Kenya (Lindgren 1988) measured maize yield increments on terraced land versus the yield from the non-terraced land, which was obtained as 47 percent in 1984/1985, and 62 percent in 1987/1988. Thus, "fanya juu" terraces increase crop productivity.

Figure 2.1. Illustration of a fanya juu terrace.



Stone Lines

In semi-arid areas where stones are plentiful, they have been used to create bunds both as a soil conservation measure and for runoff harvesting (Duveskog 2001; Thomas 1997; Critchley et al. 1992). Stones are arranged in lines across the slope to form a strong wall, and since the lines are permeable, they slow down the runoff rate, filter it, and spread the water over the field, thus enhancing water infiltration and reducing soil erosion (Critchley and Siegert 1991). In East Africa, stone lines are commonly practiced in areas receiving 200-750 mm of annual rainfall, and are usually spaced about 15-30 m apart, with narrower spacing on steep slopes, and which can be reinforced with earth or crop residues to make them more stable (Duveskog 2001). In Kenya, there is evidence that stone lines were used as a traditional soil conservation method in Baringo and Embu districts in the 1930s (Maher 1938), and are presently practiced in many parts of the country where stones are available, such as in Mbeere, Laikipia, Baringo, Mwingi, Kitui and Tharaka. In Wolloita, Ethiopia, stone lines, known locally as *kella,* are laid along the contour at regular intervals to stop soil erosion and are also constructed when fields are cleared. This method has been used for generations on the stony, sloping land in the mid-altitude zones (Hilhorst and Muchena 2000). In Tanzania, stone lines are commonly used for erosion control and to create terraces for retaining irrigation water, for example, in the Pare Mountains, Dodoma and Arusha regions (Thomas and Mati 2000; Lundgren and Taylor 1993).

Bench Terraces

Bench terraces are commonly made on steep slopes. Due to the high labor demand, they are usually made for high-value crops such as irrigated vegetables and coffee where the slopes are too steep for alternative intermittent terracing. The benches are normally designed with vertical intervals that may range from 1.2 m to 1.8 m (Thomas 1997). In East Africa, bench terraces are rarely excavated directly but instead, they are developed over time from other methods of terracing such as stone lines, grass strips and trash lines or “fanya juu” terraces, so as to reduce labor and avoid having to move large volume of soil (Wenner 1981; Mati 1984; Thomas 1997). The objective is to achieve a level bench whose slope is zero. In the coffee growing areas, benches are made to fit one or two rows of trees, thereby achieving a closer spacing. During the colonial period in Kenya, in the 1950s, bench terracing used to be forced on local people, and after independence in 1963, many terraces were destroyed or neglected. After the soil conservation extension campaigns of the 1970s-1980s, bench terraces were adopted by farmers living on steep mountain slopes of Central and Eastern Provinces, especially on farms where coffee was grown (Mati 1984; Thomas 1997).

In the drier areas, the need for water conservation has seen farmers “overdo” bench terracing so that they acquire a reverse-slope bench, meaning one with an intra-bench slope of about 2-3 percent in the opposite direction (Thomas and Mati 1999). Such a bench terrace is sometimes combined with water harvesting from an external catchment, e.g., a road, to optimize the increased storage space. The larger capacity and, the fact, that water is ponded on the upper side ensure stability of the structure. Despite the high labor demand, reverse-bench terracing in the dry areas offers a drought mitigation strategy. Reverse-bench terracing is treated as water harvesting structures and is commonly found in Mwingi, Kitui, Machakos and Makueni districts.

Kainam Terraces

Kainam terraces are an indigenous technology prevalent in the hilly area southwest of Lake Manyara, in Tanzania. It involves a system of intense and permanent cultivation of steep slopes in which terraces are made, protected by storm drains and then planted on ridges along the contour, carefully mulching and conserving moisture. Documentation on Kainam shows that the area remains well conserved, feeding some 20,000 inhabitants (Lundgren and Taylor 1993). People live in ridge communities where land is communally controlled, and cooperate through “work parties” to maintain the structures on the hillsides and drainage channels in the valleys. Livestock are not allowed to graze crop residues, which instead are dug into the fields. The soil is also enriched by manure and the crops are carefully rotated. Fallowing is practiced, albeit with shorter intervals than in the old days.

Conservation Tillage

The concept of conservation tillage, though not new, is gaining popularity in East Africa for sustainable crop production, especially in dry areas (Biamah et al. 2000; Jonsson et al. 2000). After several decades of soil and water conservation efforts in Africa, conservation tillage has been recognized as the missing link between biological methods of agroforestry, farm inputs and mechanical approaches such as terracing. The method tries to reduce labor in land preparation through tillage systems that promote soil fertility and soil water conservation. Conventionally, tillage is conducted to prepare a seed bed and also to control weeds. However, conventional tillage has been found to destroy the structure of the soil and cause compaction. This has negative effects on soil aeration, root development and water infiltration among other factors. More important, but less noticeable, is the destruction of soil microbiology by disturbance and turning over of soil, which is then exposed to drastic atmospheric and climatic conditions (Kaumbutho 2000). Conservation tillage, therefore, takes care of this by applying four main principles: 1) zero or minimum soil turning,

2) permanent soil cover, 3) stubble mulch tillage, and 4) crop selection and rotations. An important aspect of conservation tillage practice involves ripping the land with tined implements or sub-soiling the land immediately after crops are harvested, to break the plough pans. Suitable equipment includes animal-drawn sub-soilers, rippers, “ridgers”, planters, and weeders (Biamah et al. 2000; Elwell et al. 2000).

Minimum Tillage

In its extreme form, minimum tillage includes zero tillage, and/or no-till subsystems where the land is planted by direct seed drilling without opening any furrows or pits. Old crop residues act as a mulch and weeds are controlled using herbicides. In the dry areas of East Africa, zero tillage has not worked well due to poor infiltration (as soils are easily self-sealing) and costs of herbicides being prohibitive. In Kenya, “no-till systems” used to be practiced mostly under large-scale mechanized wheat/barley systems, but smallholder farmers have recently started experimenting with this system with good results, as in Machakos, Laikipia and Nyando districts. Minimum tillage also takes the form of “spot tillage” (Thomas 1997). In this case, special tools or augers are used to make small pits just for one or two seeds of grain over the old crop residues, and where the weeds are controlled with herbicides. In Arumeru District, Arusha Region of Tanzania, the digging of small planting pits with hand-hoes has been quite efficient in concentrating surface water and plant nutrients as well as breaking hard plough pans. The technique is labor intensive, but simple and is an efficient way of assuring a crop survival even when rainfall is inadequate and resources such as fertilizers and manure are unavailable. Strip tillage involves cultiating the land in strips at the position of the crop rows, leaving the rest of the land untilled, to generate runoff and reduce labor. It has successfully been practiced in Tanzania (Elwell et al. 2000). Where access to equipment is possible, the operation can be advanced to simultaneously insert seeds (and even fertilizer) into the soil while breaking the hard pan in the same single pass. Minimum tillage by plowing with a “magoye ripper,” which is adapted from Zambia has become popular among smallholder farmers in Kenya and Tanzania (Biamah et al. 2000; Lundgren and Taylor 1993). The subsoiler digs 25-30 cm into the soil breaking the plough hard pan. It can also be used to make furrows about 80 cm apart. In Arusha Region, Tanzania, where annual rainfall ranges from 400 mm-1,200 mm, the magoye ripper was found to reduce labor and enhance crop yields in the dry years (IIRR1998). Manual subsoilers have also been developed by innovative farmers (Thomas and Mati 1999). The equipment comprises a long hoe that can cut into about 30 cm of soil, which is made from old car-springs and therefore, is quite durable and cost-effective. The subsoiler is used once in 3 years, to break soil crusts developed from prolonged use of the mold-board plow.

Stubble Mulch Tillage

Stubble mulch tillage has been used as a water conservation technique in Kenya, especially in the mechanized large-scale farms growing wheat and barley as found in Kitale and Timau in Kenya (Thomas 1997; Mati 1999). Normally, this involves chopping crop residues and spreading them on the surface or incorporating them during tillage with tined implements such as the chisel plough. Stubble mulch tillage reduces labor and farm-power requirements, and, as such, it is cost-effective. Increased yields have been reported, especially in marginal areas. The system results in improved and stable soil structure, with reduced direct impact of raindrops on bare soil, thus minimizing soil erosion. Moisture retention capacity of the soil is also enhanced by the residues; hence crop survival is better during dry spells or drought. In a study at Katumani Research Station in Machakos, Kenya, Okwach (2000) obtained results showing that mulch tillage effectively reduced runoff and soil loss than that of the conventional tillage systems.

Ridging and Tied Ridges

Contour ridges (or contour furrows) involve making ridges along the contour at a spacing usually of some 1-2 m. In Kenya and Tanzania, ridging is normally done for crops such as potatoes, tobacco, groundnuts and even for maize (Assmo and Eriksson 1999). Ridging for maize involves "earthing" up the maize rows during the weeding process, albeit the maize is first planted on the flat. Plough planting is a commonly used practice in the Arusha Region (Hatibu et al. 2000). Ridging systems are mostly suited for areas with an annual rainfall ranging from 350 to 750 mm (Critchley and Siegert 1991. Among farmer innovators of East Africa, ridging has emerged as one innovation that has made a big difference in crop production (Kibwana 2000; Thomas and Mati 2000).

In the semi-arid areas, tied ridges are made by modifying normal ridges. The technique involves digging major ridges that run across the predominant slope, and then creating smaller sub-ridges (or cross-ties) within the main furrows. The final effect is a series of small micro-basins that store rainwater in-situ, enhancing infiltration. Depending on the system, the crop is planted at the side of the main ridge, to be as close as possible to the harvested water while also avoiding waterlogging in case of prolonged rains. Tied ridges have been found to be very efficient in storing the rain water, which has resulted in substantial grain yield increase in some of the major dryland crops such as sorghum, maize, wheat, and mung beans in Ethiopia (Georgis and Takele 2000). The average grain yield increase (under tied ridges) ranged from 50 to over 100 percent when compared with the traditional practice. This increase, however, will vary according to the soil type, slope, rainfall and the crop grown in dryland areas such as Kobbo, Nazreth, Meiso, Mekelle and Babilie of Ethiopia as shown in table 1.

Table 1. Effect of tillage methods on grain yield of sorghum, mung bean and maize in semi-arid regions of Ethiopia.

Soil Conservation Method	Grain yield (t ha^{-1})		
	Kobbo	Melkassa	Mean
Sorghum			
Flat planting (farmers practice)	1.6	0.8	1.20
Tied ridges planting in furrow	2.9	3.0	2.95
Mung bean			
Flat planting (farmers practice)	0.4	-	0.4
Tied ridges planting in furrow	0.7	-	0.7
Maize			
Flat planting (farmers practice)	1.2	-	1.2
Tied ridges planting in furrow	2.7	-	2.7

Source: Kidane and Rezene 1989
Note: Ridge height = 35 cm; Ridge spacing = 80 cm for mung bean, 75 cm for sorghum and maize. Ridges tied at 6-m intervals

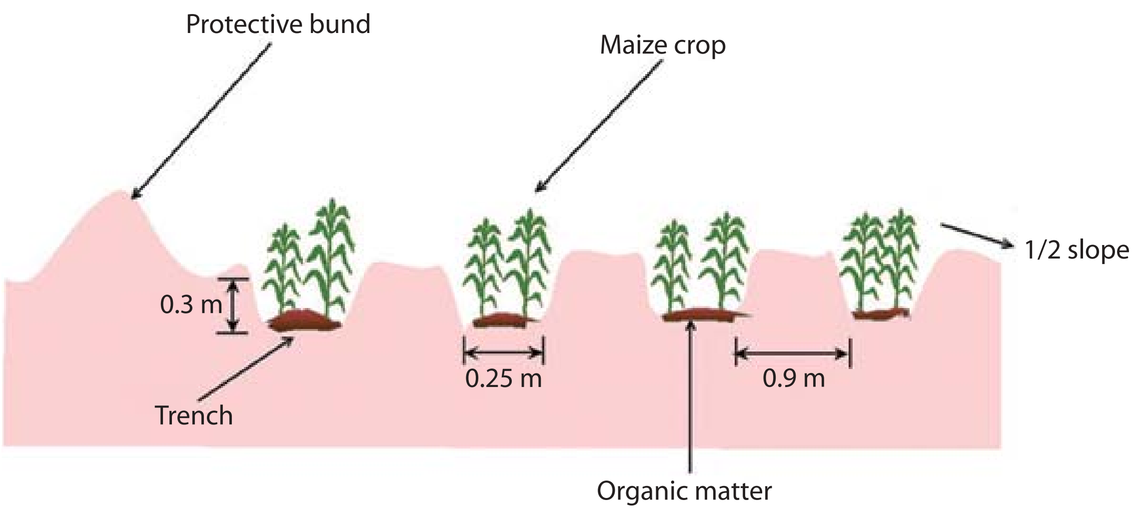
Trench Farming

Trench farming is a variation of pitting, but the trenches are normally meant for incorporating large amounts of organic matter in the soil, and thus may end up being higher than the ground. The purpose is three-fold—to improve soil fertility, infiltration and moisture storage capacity (Hamilton 1997). The Kenya Institute of Organic Farming (KIOF) has been working with farmers in trials of trench farming, which is sometimes known as "ridge and furrow system" of farming (figure 2.2). In Kirinyaga District of Kenya, trench farming is achieved by creating large beds, which are about 2.5 wide, intervened by furrows of same width, and are about 1.3 m deep. On top of the ridge, sweet potatoes are grown, both for their fodder and tubers, while the furrow is used for growing napier grass. The idea is to retain moisture in the furrow longer, and thus get fodder even during the dry season. Sometimes, bananas are grown in holes within the furrow, thereby allowing them to use even deeper layers of water during the dry season, and thus achieve better production. The system allows the farmer to get fodder even when the dry season is prolonged, due to the good moisture storage, and as such, many farmers are adopting the system.

In the Dodoma Region of Tanzania, trench farming involves maximizing soil moisture storage in the crop root zone by burying as much vegetative material as possible. A case study by (Critchley et al. 1999) shows how a farmer has perfected the system of trench cultivation. Trenches measuring 0.6 m deep and 0.6 m wide are dug across the slope, at a spacing of 0.9 m apart, edge to edge. The trenches are then filled with crop residues, grass and other organic trash, and finally backfilled with soil, to leave the cropped area, which is about 0.15 m below ground level so that it can capture runoff. The trench stores enough moisture to guarantee a crop yield even when there are only 2-weeks of rainfall. The trench can be re-used with good results for up to four crop seasons.

In the low rainfall areas in parts of southern Ethiopia, farmers have developed a highly specialized trench farming system. The land is prepared in multitudes of circular depressions (3 to 4 m in diameter and less than 1 m deep) where a variety of crops are inter-cropped. There is literally no runoff from the fields. In good years, all crops are harvested (SIWI 2001).

Figure 2.2. Illustration of a trench farming system.



Silt Borrowing and Trapping

Soil borrowing from rich valleys to top-dress degraded areas has been used for rehabilitating degraded lands in Kenya and Tanzania. The Promoting Farmer Innovation (PFI) Project (Critchley et al. 1999) identified several farmers in both countries who were using soil-harvesting techniques to improve soil fertility and/or moisture retention properties (Mutunga et al. 2001; Critchley et al. 1999). In Mwingi District, Kenya, two farmers, Kamuti Nthiga and Manzi Kavindu were independently trapping the silt fraction of the flood waters from seasonal rivers with amazing success, to build up a soil layer for growing sugarcane and fodder grass. In Dodoma, Peter Wilson and Hosea Mhuma, invented a system in which they would ferry soil using wheelbarrows from nearby hills to cover and reclaim eroded/gullied land, creating enough soil depth for irrigated high-value vegetables (Thomas and Mati 1999).

Gully Control and Utilization

Gully erosion is a major problem in East Africa, and with the high costs associated with gully rehabilitation, most gully control activities have, in the past, been implemented by the government or with external assistance. Moreover, most gullies lie on public land, e.g., grazing lands, footpaths and farm boundaries. As such, the responsibility for their rehabilitation is usually beyond the scope of the individual. Studies in Kiambu District of Kenya (Mati 1984) showed that over 50 percent of the gullies emanate from road drainage. Thus in the early 1990s, soil conservation activities were introduced into road rehabilitation projects to protect land from damage caused by road drains (Mati 1992). However, even then, the main aim was to drain away surface runoff, which was seen as a destructive problem. These perceptions were later changed in the early 2000s to embrace the concept of water harvesting, even from gullies, for productive purposes. At last a gully could be viewed as an asset, and this was recorded in many parts of the country. Innovative farmers have been able to convert gullies into productive land in Mwingi, Makueni and Kitui districts. (Mburu 2000; UNDP/UNSO 1999; Critchley et al. 1999). In one such case, farmer Mutembei Mwaniki of Mwingi reclaimed a gully with stone walls, well designed and complete with side spillways, and thus established level beds for cultivation of field crops through the gradual accumulation of sediment. He used stone check dams to trap sediments in the gully, in stages. Whenever a layer of silts built up, he would increase the height over the existing stone check by about 0.3 m. At the deepest point, there was up to 3 meters of sediment accumulated. The total area reclaimed was around 500 m^2. The rehabilitated gully was supporting the cultivation of bananas and papaya as well as green maize. He was successful in obtaining a good yield from his crops, even as his neighbors' crops failed (figure 2.3).

Gully control activities have been undertaken in the Arusha Region of Tanzania (Assmo and Eriksson 1994), where farmers have been innovative and successful in rehabilitating gullies on their farms and converting them to productive land. In Dodoma, farmer Raphael Chinolo and his wife controlled a gully system by planting bananas in deep pits (Critchley et al. 1999). They would fill each pit with 20 liters of manure before planting. The pits capture runoff, but to give extra control of overland flow, they made terraces of earth bunds 0.6 m high, upon which they planted makarikari grass for stability. This way, they were able to stop gully development, increase crop production, improve soil fertility, harvest runoff water and reduce soil erosion.

Figure 2.3. Rehabilitation of a deep gully to form a cropland.

In Ethiopia, gully control has been carried out mainly using stone check dams, with U-shaped and parabolic spillways. These check dams have been quite effective in smaller and average size gullies, but bigger ones needed more sophisticated control structures (Wolde-Aregay 1996). In Tigray region, gully reclamation for productive purposes has been practiced with favorable agronomic results. This has improved the potential for successfully cultivating banana, elephant grass and sugarcane on previously gullied land, albeit with complex socioeconomic implications (SIWI 2001). Unclear land tenure created various difficulties in privatizing the reclaimed gully, which led to the progressive abandoning of crop husbandry in the gullies. Vegetative gully control has not been popular owing to lack of materials and also due to the problem of free grazing. Another basic rule of gully control, that of avoiding plowing right up to the edge of gullies, was not followed because of the smallness of most landholdings (Wolde-Aregay 1996).

Ngolo Pits

The Wamatengo people of Matengo highlands in Mbinga District in Tanzania have a unique indigenous farming system, known as “ingolu” or “ngolo” or simply “matengo pits”. This is characterized by a combination of soil conservation techniques of pits and ridges on slopes about 35-60 percent steepness (Temu and Bisanda 1996). A major feature of the ngolo system is that the fields contain a large number of pits. This system can be classified as “grassland fallow farming,” although the cropping is usually repeated for many years without fallow. It is also combined with a two-crop-rotation system in which beans (*Phaseolus vulgaris L.*) are planted in the late rainy season of the first year and maize in the following year. As the ngolo farming system is repeated in a 2-year cycle and as maize and beans are the two main food crops for the people of Matengo highlands, they need to own at least two fields. In the event of a decrease in the maize yield, the field is fallowed for several years until it is fully covered with shrubs or tall grasses (Tarimo et al. 1998). When a maize crop that has been grown under the ngolo system of farming was compared with a similar crop obtained through terracing methods (Edje and Samoka 1996), the yield from the ngolo system was found to be superior as shown in table 2.

Table 2. Maize yields (as % of highest) in ngolo and other cultivation systems.

Cultivation systems	Yield (%)
Ngolo	100
Flat cultivation	49
Constructed bench terraces	44
Ridges	43
Narrow-based contour banks	27
Formed bench terraces	22

Source: Edje and Semoka 1996

The ngolo system is also characterized by its land use in the early rainy season of the first year. In the month of March, the men cut the well-grown weeds in a system known as “ku-kyesa”, which requires cutting the weed as close to the ground as possible. The cut shoots are left for 2 weeks to dry. The dry shoots are next gathered up into lines by a billhook. The lines stretch both vertically and horizontally forming a grid of 1.5-2.0 m squares. The size of the square determines the density of the plant population. This task is called “ku-bonga,” and is done by men. The well-ordered lines become a basic design for the following work. The shoot bundles forming the lines are called “mabongi,” and all weeds growing on the field and maize stalk residues are used for it. Thereafter, the mabongi are covered with soil, forming ridges at most 20-30 cm wide and 10-20 cm high. The size of the ridge affects the density of the plant population and the water-holding capacity of the pit. After finishing “ku-bonga” on a specified area, women cover “mabongi” with small amounts of topsoil in a square. Then they broadcast bean seeds on the small ridges and cover the seeds with soil. Throughout the next dry season a ngolo field is kept fallow, and at the beginning of the rainy season, maize is planted on the ridges where beans had been grown. The seeds are sown along the contour line. When maize reaches 20-30 cm in height, the weeds are removed and the sediment at the bottom of the pits are dug up by a hoe and used to re-build the “mabongi.”

WATER HARVESTING TECHNOLOGIES

Interest in water harvesting is growing in East Africa, as more people are beginning to realize that surface runoff is a resource as important as the rain, and that it can be used for sustainable crop production and/or livestock watering. Consequently, there has been a major development in a diverse range of technologies in water harvesting and conservation. This has been attributed, in part, to the transition from the imposed top-down rural development approaches to the more progressive adoption of community-based participatory approaches (Lundgren 1993). These have probably favored the development of the diversified set of runoff farming techniques. Today, one can see these techniques being used in various farming systems in the region. RWH systems are also applicable over a wide range of conditions in areas where average annual rainfall is insufficient to meet the crop water requirement, with seasonal rainfall being as low as 100 to 350 mm (Oweis et al. 2001; Critchley and Siegert 1991; SIWI 2000).

Innovations by progressive farmers seem common in the field of runoff farming (Mburu 2000; Kibwana 2001). Farmers observe the flow of surface water through their own watersheds, and based on experimentation on trial and error basis, sophisticated runoff farming systems are developed (SIWI 2001). This can, for example, be the tapping of sheet flow from roads, diversion of sheet flow from rocky areas adjacent to the farmland, or diversion of surface runoff from footpaths. Runoff farming systems play an important role in small-scale farming practices, which is explained by the fact that: (i) the techniques are easy to design, (ii) runoff volume is reasonably limited (sheet and rill runoff), which means that the farmer can control the inflow of water with little effort, and (iii) relatively simple methods and a significant volume of water can be added to crops during rainfall periods.

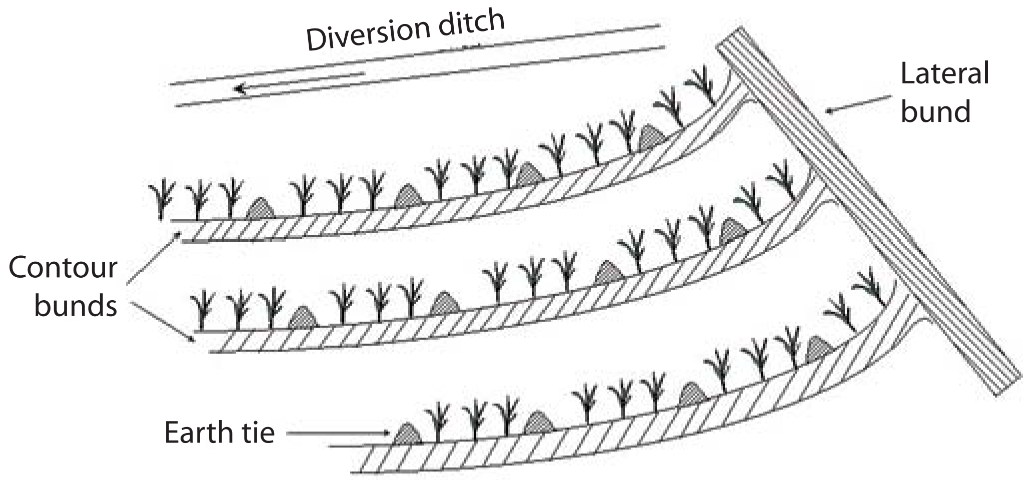
Micro-catchment Systems

Micro-catchment systems are basins, pits, bunds and all other water harvesting systems that get their runoff from small areas. A portion of upslope land is allocated for runoff collection, which is "harvested" and directed to a cultivated area (cropped area) down slope. Micro-catchments are normally within-field systems (Critchley and Siegert 1991; Hai 1998) since runoff comes from within the vicinity of the cropped area. The systems, generally, have a ratio of catchment to cultivated area ranging from 1:1 to 5:1. The Soil and Water Management Research Group at Sokoine University, Morogoro, Tanzania has carried out extensive research on what are known as "meskat" systems (SIWI 2001; Hatibu and Mahoo 2000). Their research, in a semi-arid area, suggests that the systems give significant yield increases on the runoff receiving proportions of the land, but that farmers are not willing to adopt the system due to the significant amount of land they have to give up for this purpose. There are many types of both micro-catchment and external catchment systems practiced in East Africa, such as semi-circular bunds, "negarims" (a newer micro-catchment method of utilizing basins) and earth bunds.

Earthen Bunds

Earthen bunds are various forms of earth-shapings, which create run-on structures for ponding runoff water. The most common are within-field runoff harvesting systems, which are increasingly gaining popularity among smallholder farmers in East Africa. This may be due to the fact that farm units are small, and sometimes have no opportunity for tapping an external catchment. Within-field systems also tend to require less mechanization, relying more on manual labor and animal draught. In design, the soil bunds are aligned along the contour, with spillways at 20 m intervals to control the application of surface water in each bund-section where the crop is cultivated. Bunds are set at 15-20 m intervals and the catchment to cultivated ratio ranges from 5:1 to 20:1 (Pacey and Cullis 1986). There should be a deliberate effort to distinguish bunds meant for within-field water harvesting and those meant for conventional soil and water conservation (figure 3.1). Under the runoff harvesting system, a "catchment" is maintained within the terrace to provide runoff that will add to the natural rainfall, while under conventional bunding, the whole terrace is cultivated.

Figure 3.1. Contour bunds for field crops.



Trapezoidal Bunds

Trapezoidal bunds have an indigenous origin and are used by farmers in several arid and dry semi-arid environments in the Horn of Africa (Kenya, Somalia and Sudan). They are, generally, constructed by hand and used for subsistence cultivation. An example is one called the"teras" system, a widespread system of large earth bunds with straight walls, used to cultivate drought-tolerant crops, e.g., sorghum, in areas with a low annual rainfall of 150-300 mm (van Dijk and Reij 1994). Trapezoidal bunds are large structures, sometimes over 100 m long along the contour with the wing walls turned about 135 degrees facing upslope. The bunds are usually spaced about 20 m apart, and overflow arrangements are made in a way that excess runoff from one bund can find its way to the next. Field crops such as sorghum and millet are grown in the basins. Trapezoidal basins of this nature utilize external catchment or runoff from beyond the immediate cropped area.

Examples of these have, as described by Critchley and Siegert (1991), been used to rehabilitate semi-arid areas of Turkana and Baringo districts of Kenya. The main concern is whether trapezoidal bunds are socioeconomically viable depending on labor costs, and what equipment is used to construct them. Over the years, lack of mechanization and implements has seen their adoption decline in East Africa. Perhaps, with new advances in animal draught and other affordable mechanization technologies, renewed research into adaptable trapezoidal bunding is called for, as it is possible to treat large areas quite efficiently using this method.

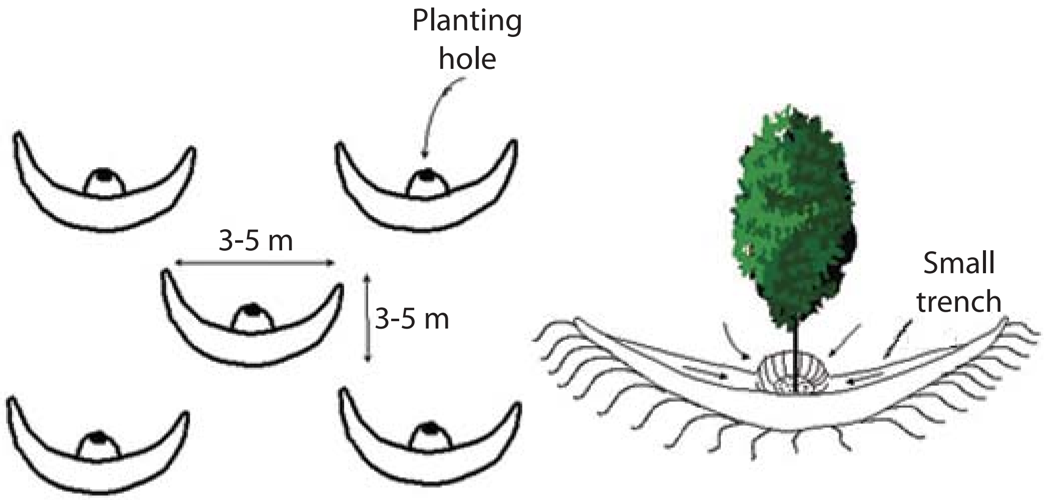
Runoff from Hillsides and Rocks

Sometimes large rocky surfaces and hillsides are used as a source of runoff. This is channeled into large basins, created by making large bunds around them (Critchley and Siegert 1991). Research in Baringo District of Kenya (Imbira 1989) showed that due to the high runoff producing characteristics of the hillsides, rainfall storms of as little as 8 mm were able to initiate surface runoff. In field trials using runoff-harvesting system with a catchment size of one hectare, 48 percent of showers greater than 10 mm produced sufficient runoff to cause inflow into bunded basins. Field crops such as sorghum and millet could be grown in otherwise very arid conditions.

Semi-circular Bunds

Semi-circular bunds (also known as demi-lunes or crescent-shaped bunds) are commonly made in the semi-arid areas of Kenya, Ethiopia and Tanzania for runoff harvesting of young tree seedlings. The normal designs (Hai 1998; Critchley and Siegert 1991; Duveskog 2001) involve making earth bunds in the shape of a semi-circle with the tip of the bunds on the contour (figure 3.2). In Busia District of Kenya, semi-circular bunds are made by digging out holes along the contours. The dimensions of the holes and the spacing of the contours are dictated by the type of crop or the farming system. For common fruits, the holes are made with a radius of at least 0.6 m and a depth of 0.6 m. The sub-soil excavated from the pit is used to construct a semi-circular bund with a radius ranging from 3 m to 6 m on the lower side of the pit. The bund height is normally 0.25 m (Bittar 2001). The excavated planting pits are filled with a mixture of organic manure and topsoil to provide the required fertility and also to help retain the moisture. It is a common practice to find farmers planting seasonal crops such as vegetables including beans, and other herbaceous crops in the pits before the tree-crop develops a shady canopy. Semi-circular earth bunds are found in arid and semi-arid areas, where annual rainfall ranges from 200 mm to 275 mm, and land slopes are less than 2 percent steepness for both rangeland rehabilitation and annual crops (Thomas 1997). Sometimes, semi-circular bunds are made larger for rangeland rehabilitation and fodder production. When used for growing of trees, the runoff water is collected in an infiltration pit at the lowest point of the bund, where the tree-seedlings also are planted. The bunds are laid out in a staggered arrangement so that the water which spills round the ends of the upper hill will be caught by those lower down. The main problems associated with this type of bund are: 1) they are difficult to construct with animal draft; and 2) they require regular maintenance.

Figure 3.2. Illustration of the layout of semi-circular bunds.

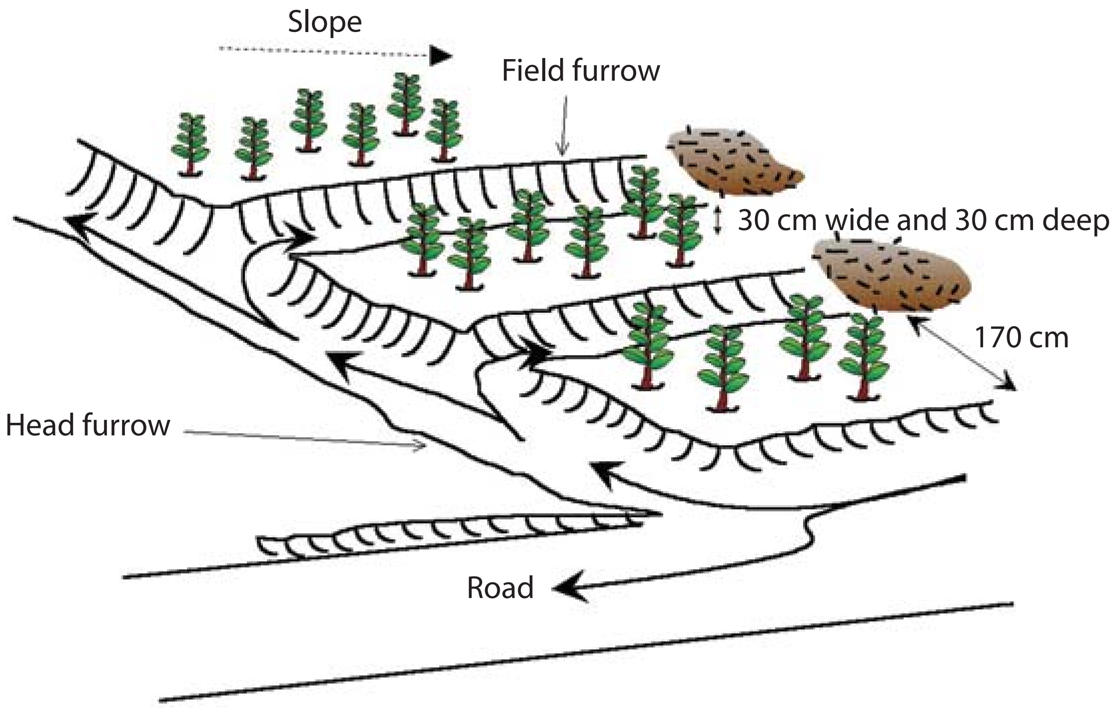


Broadbed and Furrow

Broadbed and furrow systems are a modification of contour ridges, with a deliberate effort to ensure that there is a "catchment" ahead of the furrow, and there is a within-field micro-catchment water harvesting system (figure 3.3). In Ethiopia, Kenya and Tanzania, the systems are made as small earthen banks with furrows on the higher sides, which collect runoff from the catchment area between the ridges. The catchment area is left uncultivated and clear of vegetation to maximize runoff. Crops can be planted on the sides of the furrow and on the ridges. Plants that need much water, such as beans and peas, are usually planted on the higher side of the furrow, and cereal crops, such as maize and millet, are usually planted on the ridges. The distance between the ridges varies between 1 m and 2 m depending on the slope gradient, the size of the catchment area desired and the amount of rainfall available. Contour furrows are used in areas where the annual rainfall is from 350 mm -700 mm (Duveskog 2001). The topography should be even to facilitate an equal distribution of water. Contour furrows are most suitable on gentle slopes of about 0.5-3 percent steepness. Soil should be fairly light. On heavier, more clayey soil they are less effective because of the lower infiltration rate. Although the contour furrows increase crop yields in the drier areas, the labor requirements are higher than for conventional farming, and the intricacies involved in making them (contour furrows) deter many farmers from adopting them.

Critchley et al. (1992) describe contour furrows in the Baringo District of Kenya as small earthen ridges, which are ranging from 0.15 m – 0.2 m in height. These ridges are spaced at approximately 1.5 m apart on the contour. The furrow, which is upslope, accommodates runoff from an uncultivated catchment strip between the ridges. Small earthen ties were made within the furrow at a spacing of 4 m-5 m to prevent lateral flow. The objective of the system was to concentrate local runoff and store it in the soil profile, close to the plant roots. These types of contour ridges were designed for small-scale production of food crops. A cereal intercropped with a pulse was the recommended system. As this is a micro-catchment or within-field catchment system, runoff from an external source is not required and, it may even damage the structures. To prevent the risk of overflow within the system, a cutoff drain is, therefore, provided where necessary. Contour ridges may be used on a range of slopes, though dimensions need to be increased as the gradient increases.

Figure 3.3. Broadbed and furrow system.



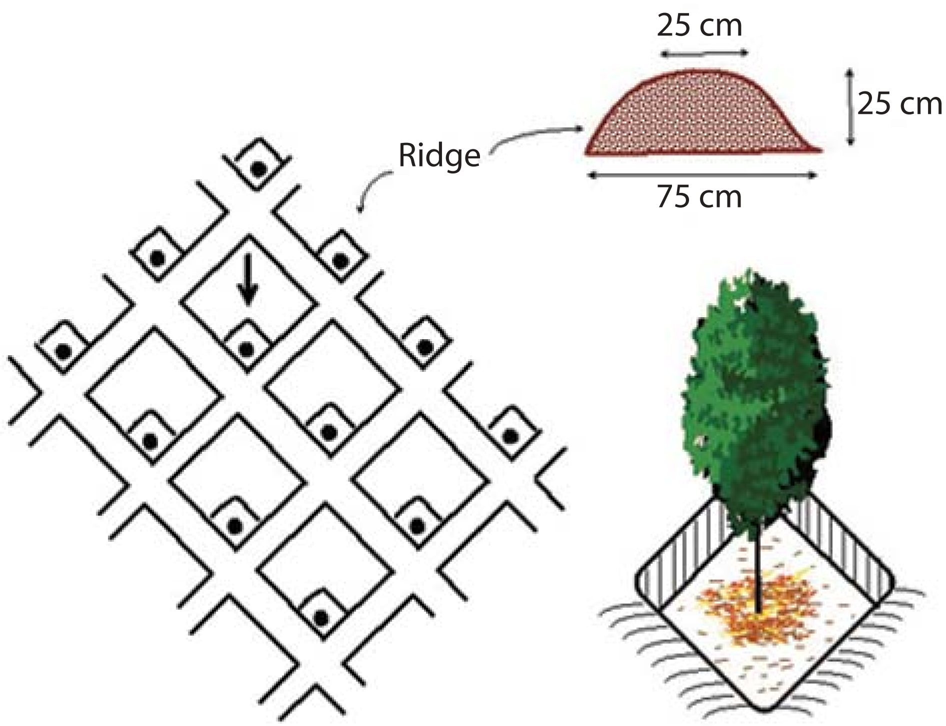
Basins

Earth basins are normally small, circular, square or diamond shaped micro-catchments, intended to capture and hold all rainwater that falls on the field for plant use. Basins are constructed by making low earth ridges on all sides, to keep rainfall and runoff in the mini-basin. Runoff water is then channeled to the lowest point and stored in an infiltration pit. Earth basins are suitable in dry areas, where annual rainfall amounts to at least 150 mm, slope steepness ranges from flat to about 5 percent, and soil that is at least 1.5 m deep to ensure enough water holding capacity. Earth basins have proven successful, especially for growing fruit crops, and where the seedling is usually planted in or on the side of the infiltration pit (Duveskog 2001). The size of the basins may vary between 1 m to 2 m in width and up to 30 m in length for large external catchments. The main limitation is the need to use a vast amount of land in comparison to the crop grown (Critchley et al. 1992). There is also the danger of breaching in the event of unexpectedly high rainfall. In the northern province of Tigray, micro-basins measuring about 1 m long and 0.5 m deep are often constructed along these retention ditches for the planting of trees. In the Axum area, in northern Tigray, these retention ditches while preventing a large volume of surface runoff from flowing down the steep escarpments, have facilitated the revival of natural springs that, according to the local communities, had dried out probably due to severe upstream deforestation.

Negarims

"Negarims" are a newer micro-catchment method of utilizing basins, which have been adopted from the Negev Desert of Israel. They are used for the establishment of fruit trees in arid and semi-arid regions where the seasonal rainfall can be as low as 150 mm (figure 3.4). In design, they are regular square earth bunds, which have been turned 45 degrees from the contour to concentrate surface runoff at the lowest comer of the square (Hai 1998; Critchley and Siegert 1991); they are, therefore, efficient in land utilization (figure 3.4). Negarims are practiced in Kitui, Thika and Meru districts of Kenya for fruit tree production (Hai 1998).

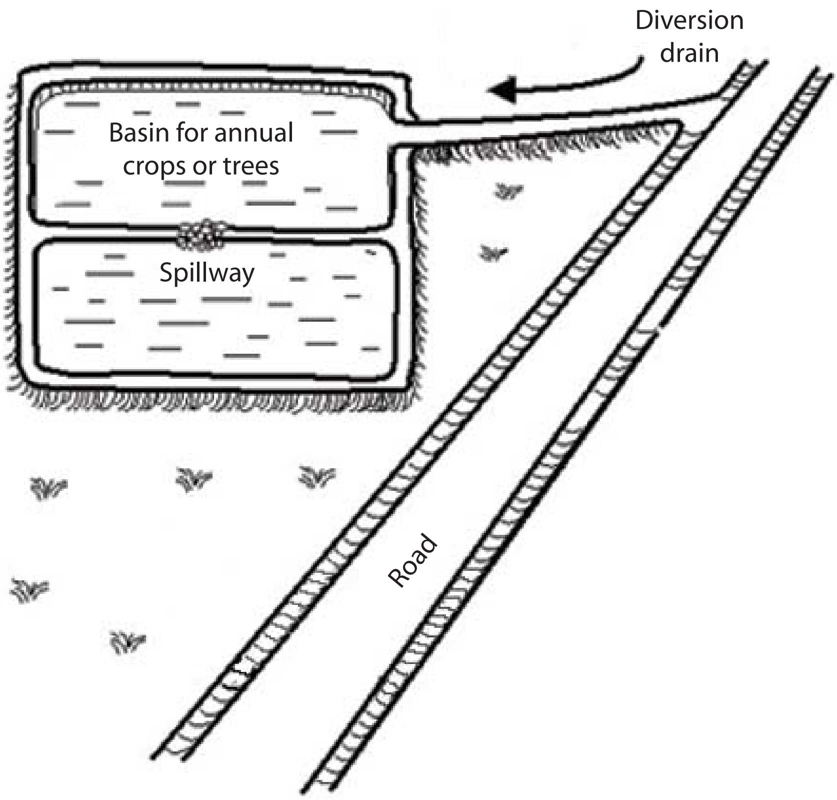
Figure 3.4. Negarim micro-catchments for tree crops.



Excavated Bunded Basins (majaluba)

Excavated bunded basins (or *majaluba* in Kiswahili) are widely used in the semi-arid areas of Mwanza, Shinyanga, Tabora, Singida and Dodoma regions, of Tanzania, and have become the most important source of paddy rice in the country (Hatibu and Mahoo 2000; Hatibu et al. 2000). Majaluba are constructed by digging to a depth of 0.2 m to 0.5 m, and by using the scooped soil to build a bund around the field perimeter (figure 3.5). Normally, the bunds have a height of between 0.3 m to 0.7 m above the ground. Farmers usually start with small-sized majaluba, for example, 10 m by 10 m, and then go into large areas of about 1 ha. This system is one of the methods of runoff utilization, management and storage for the production of paddy rice.

Figure 3.5. Excavated basins for road runoff harvesting.



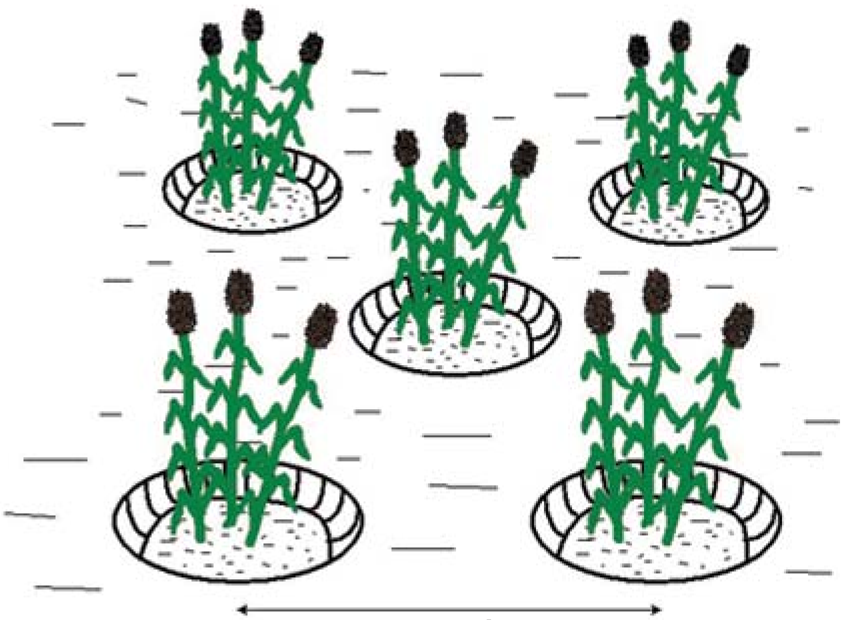
Pitting Systems

Pitting (digging of holes of various sizes for growing crops) has been practiced as a method of water harvesting and conservation for both micro-catchment and external catchment systems. Pitting in East Africa has always been done for special crops such as bananas, coffee, tea and many different types of fruit trees. However, pitting for field crops such as maize, millet and beans is still viewed as novel. Pitting is done to store water and to build up soil fertility.

Zai Pits

The "zai" system has been adopted from the Sahel Region of West Africa (Critchley and Siegert 1991; Reij et al. 1996) where it has been practiced for centuries. In Kenya, zai pits have been experimented with good results (Hai 1998). The zai utilizes shallow, wide pits that are about 0.6 m in diameter and 0.3 m in depth, in which four to eight seeds of a cereal crop, e.g., maize, are planted (figure 3.6). Manure is usually added into the pit to improve fertility. It works by a combination of water harvesting and conservation of both moisture and fertility in the pit. There have been some modifications of the zai system. At the Kenyan Agricultural Research Institute (KARl) at Katumani, in the Machakos District of Kenya, a locally adapted manual pitting system has been developed (also called the "katumani-pit"), which is similar to the small zai-pit. In the Njombe District of southern Tanzania (Malley et al. 1998), the pits are made bigger and deeper (at least 0.6 m deep), and a 20-litre volume of manure is added. Since the area receives an annual rainfall close to 1,000 mm, the farmers plant about 15-20 seeds of maize per pit and the yield is more than double of those on conventional tilled land.

Figure 3.6. Zai pits for water harvesting and conservation.



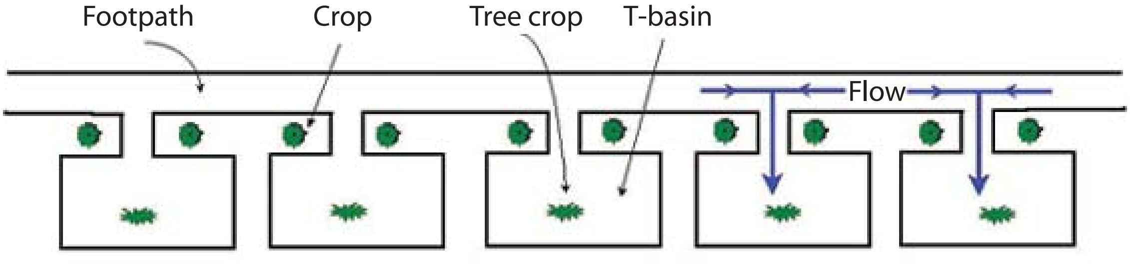
Chololo Pits

"Chololo" pits are so named after the village where they were invented by Kenneth Sangula of Dodoma Region in Tanzania (Critchley et al. 1999, Mutunga et al. 2001). It is a pitting method, which is a modification of the zai pits of the Sahel, but Kenneth said that he discovered the innovation almost by accident. In design, chololo pits comprise a series of pits, which are about 22 cm in diameter and 30 cm in depth. The pits are spaced 60 cm apart within rows, and 90 cm between rows, with the rows running along the contour. The soil removed during excavation is used to make a small bund around the hole. Inside the pit, ashes (to expel termites), farmyard manure and crop residues are added, then covered with the requisite amount of soil while retaining sufficient space in the hole for runoff to the pond. The aforesaid preparations ensure the water infiltrated is held by the organic materials, thereby allowing moisture retention to last longer. One or two seeds of either maize/millet or sorghum are planted per hole. Crops usually survive even during periods of severe rainfall deficits, while yields have been noted to triple. Because relatively less labor is required for digging the smaller holes, this method has been adopted by many farmers, and is easily transferable (Lameck personal communication).

T-basins

Another technique practiced in Kenya, which utilizes external catchments, is locally known as T-basins (Bittar 2001). A series of interconnected basins (T-shape in form) (figure 3.7) are connected to external catchments such as footpaths and roads through a system of narrow channels. The water generated from the catchments is conveyed to the basins via the channels. The water collected in this manner is held in the T-basins, from where it infiltrates into the root zone of the surrounding crops. As opposed to the circular root zone basins, this system can be used for both tree and

Figure 3.7. Arrangement of T-basins.



non-tree crops. Traditionally, the system is used by farmers in Nambale Division of western Kenya for growing bananas, mangoes, citrus and passion fruit (Bittar 2001). This method is used also in Mwingi *(*Mburu personal communication*)*.

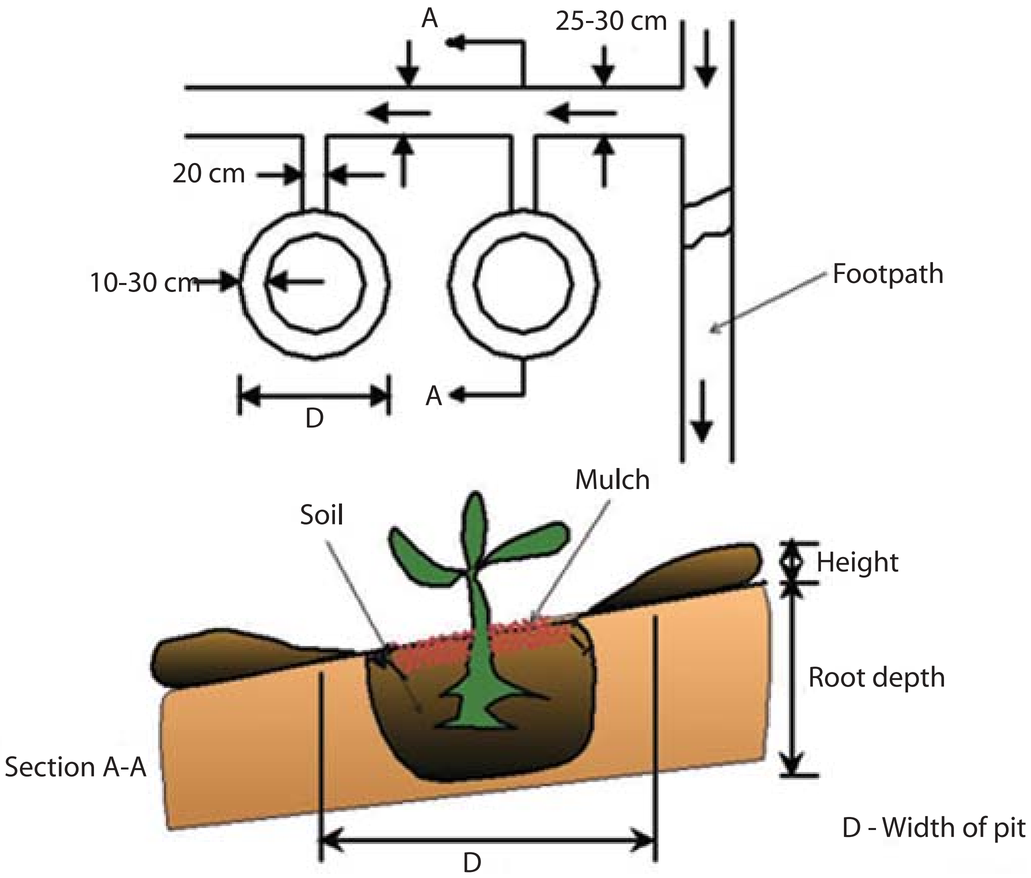
V-basins

Basins and pitting have for long been utilized for tree crops. One design used in the Turkana Region of Kenya, as described by Critchley et al. (1992), was in the form of a "V" shape (with arms extending upslope for 10 m and then tips on the contour). The excavated pit, in the angle of the V was 2.5 m^3. There is no precise spacing between individual micro-catchments, in practice, however, the catchment area can be up to 150 m^2 in the driest areas. In certain more favorable zones, an alternative design is used for individual catchments of 5 m by 5 m and pits of 1.2 m^3 capacity. Tree seedlings are planted behind each pit, immediately after the beginning of the rains.

Root Zone Basins

Root zone basins adopt the form of circular pits (which are deeper than average pits) to provide adequate moisture storage in order to reduce breakage of basin walls (Bittar 2001). The common dimensions of basins, as applied by the farmers are 0.6 m to 1.2 m in diameter, and 0.1 m to 0.3 m in bund-height (figure 3.8). The depth of tillage within the basin is usually increased up to 0.6 cm with a view to improve root zone storage capacity for the harvested water. Moisture retention in the root zone is enhanced through addition of manure, mulching and using vegetative materials. Root zone basins are predominantly external catchment systems utilizing runoff (paths, roads and compounds) with the use of slightly raised bumps, which are about 0.05 m high across the path, into collecting channels, and from there the water is directed into the basins.

Figure 3.8. Schematic representation of the root zone basin.



Five by Nine Pits

"Five by nine" are planting pits for maize crops, which are 60 cm square and 60 cm deep. They are larger than zai pits but have a square shape. The name "five by nine" is based on the five or nine maize seeds planted at the pit diagonals (five for dry areas and nine for wet areas). This type of pit can hold more manure than a zai pit. Hence, it is capable of achieving higher yields that have a long-lasting effect. The system has been popularized by the Kenya Institute of Organic Farming (KIOF) — (IIRR 1998), especially in Kirinyaga, Mbeere, Murang'a and Machakos districts of Kenya, where farmers have successfully maximized production on their farms through this system. Moreover, the pit can be re-used for a period up to 2 years.

Tumbukiza Pits

Another pitting system modified to revolutionize fodder production and improve soil fertility is a method known as "tumbikiza". *Tumbukiza* in the Kiswahili language means, "throw all in." The method involves digging huge pits, which are about 0.6-0.9 m in diameter and with similar dimensions in depth (Mati and Mutunga 2005). The pits are then filled with trash and vegetative material, including farmyard manure and topsoil. A fodder crop is usually grown in the tumbukiza pit, preferably napier grass. In the Nyando District of Kenya, farmers apply one 20-litre jerrican of water per hole per day during the dry season. This amount of water is well retained by the vegetative material in the pit, enabling the napier grass to grow rapidly and thereby make it possible to have one cutting per hole per day. Thus, a farmer with one cow needs 30 pits, which he/she waters at one jerrican a day to get enough fodder for the cow for the month. At the end of one cutting cycle (30 days), the fodder has grown enough to allow the next round of cutting (Mati and Mutunga 2005). This method has been so popular that farmers have been adopting it all over the country. However, the high labor demand in excavating the pits has discouraged their adoption among the poor.

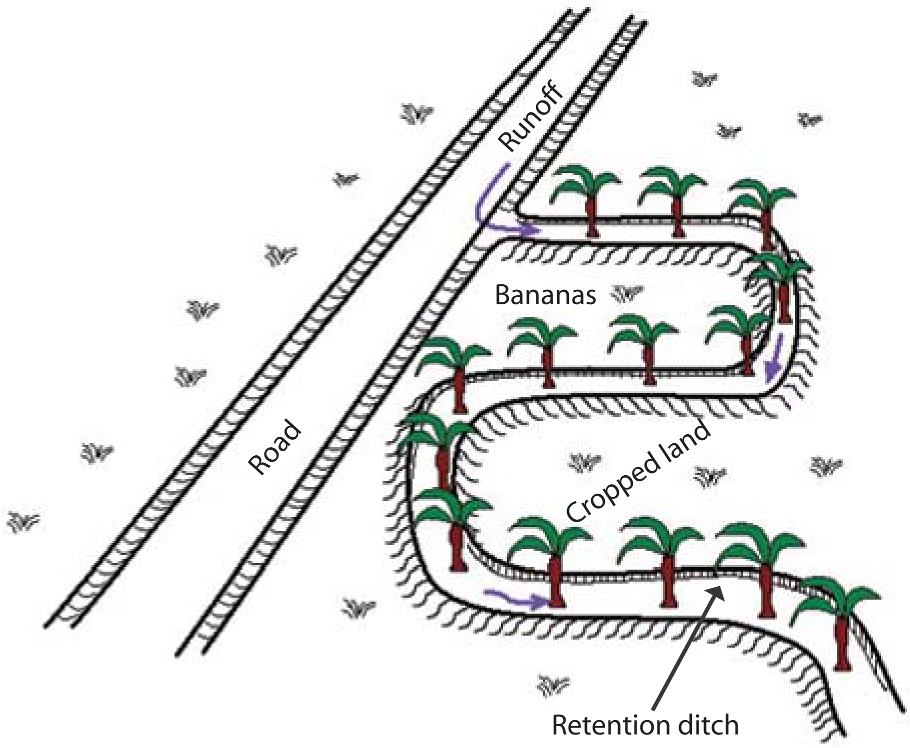
Runoff Harvesting from Roads, Footpaths and Compounds

Runoff harvesting from roads, footpaths and compounds is a practice that is currently not so widely practiced considering its potential replicability throughout the region, with the exception of Tanzania. The systems can be used for either (i) "blue" water or (ii) "green" water harvesting. Footpaths, dirt roads and compounds consist of compacted soil, often with heavy erosion crusts that produce high volume of runoff. These are used to harvest runoff upstream for productive purposes. In many parts of East Africa, farmers have developed simple runoff farming techniques, where "sheet and rill" runoff generated from compacted surfaces such as roads, footpaths and household compounds is diverted either directly into cropped land or storage structures such as ponds.

Road runoff harvesting systems vary from simple diversion structures directing surface water into crop fields, to deep trenches with check-dams in order to enable both flood and subsurface irrigation (Thomas 1997; Hatibu et al. 2000). Where surface conditions permit, storage in pans can be quite cost-effective, as has been demonstrated by farmers of Lare in the Nakuru District of Kenya (Tuitoek et al. 2001). In a project where over 1,000 pans were dug to trap road runoff, the area was transformed from a food-aid recipient to a net exporter of food through this technology. In Tanzania, tapping road runoff for supplemental irrigation crops is widespread. (SIWI 2002). In another case at Adigudum in Tigray, Ethiopia, farmers improved a borrow site into a dam that stores water for livestock use, thereby reducing the distance livestock have to walk to water, especially during the dry season (Haile et al. 2000).

One case study describes a method of road runoff harvesting developed by farmer Musyoka Muindi of Mwingi District, Kenya, which has become a standard design quoted in text books. The system comprises an excavated main channel of about 300 m in length, which diverts road runoff from the road to the farm. Once in the farm, the runoff is led first into a channel made across the predominant slope, popularly known as "fanya chini" (rather like a diversion ditch). At the end of this channel, the water is diverted around a bend into a similar channel, this time, the flow being in the opposite direction. This system is repeated throughout the farm resulting in a zigzag reticulated flow (figure 3.9). At certain points, in specific channels, the farmer puts water control gates in order to determine the direction of the flow. The channel dimensions are about 1.0 m deep and 1.0 to 2.0 m wide, and with earthen embankments which are 1.5 m high and spaced at 18 m apart, making them somewhat larger than the average size. The vertical intervals between structures are thus about 0.9 m. The embankments are stabilized with grass or sugarcane (Mutunga et al. 2001).

Figure 3.9. Road runoff harvesting into channels for crop production.



Runoff from Railway Lines and Borrow Pits

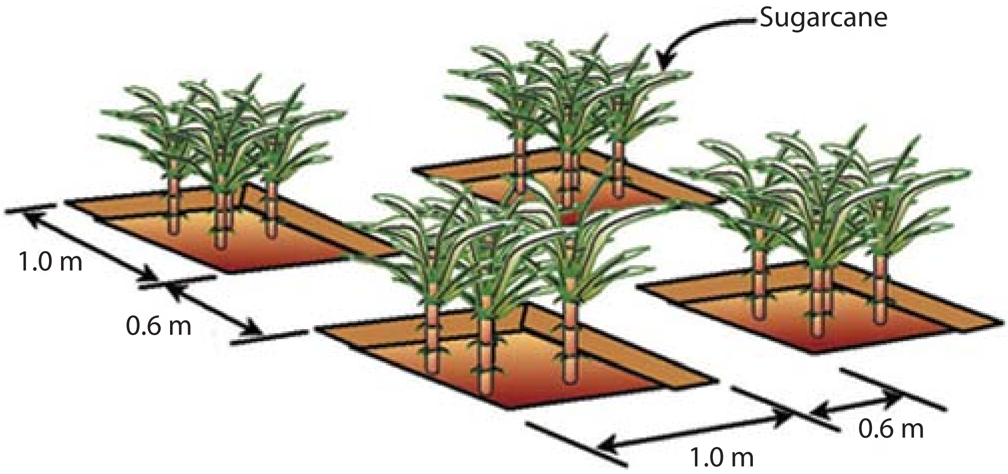
Although railway lines are few and far between, they are used for water harvesting in many parts of Tanzania. Due to the paved nature and the fact that they are usually built to lie above adjacent lands, they are a good source of runoff by gravity flow. In semi-arid Singida, Tanzania, railway culverts are used to collect runoff, which is used to irrigate about 150 ha of farmland by smallholder farmers (SIWI, 2001). In other areas, farmers use the pits found at roadsides (created when "murram" is dug out for road construction) as an important source of domestic and agricultural water. The scope to link infrastructural development with water provision and, indeed, rain-fed agriculture is greatly underestimated.

Utilization of Riverbeds and High Water Tables

In the ASAL areas, utilization of residual moisture in sand rivers and seepage from streams has been used to grow crops as a traditional practice throughout Africa. Generally, "women's crops" such as arrow roots, sweet potatoes, fruits and vegetables were grown in the valley bottoms ensuring better nutrition for the family. Sugarcane and rice have also traditionally been grown in river valleys. Valley bottoms are very important for providing food security in semi-arid areas prone to regular droughts. An analysis of farmer innovators in Mwingi District of Kenya, revealed that approximately half of all innovations in soil and water management were to be found along dry riverbeds (there being no permanent rivers in the district). In addition, the farmers consider that water table management to be easy and, therefore, adoption of related innovations has been good (Mburu 2000).

Innovative methods of utilizing riverbeds and high water tables were found among farmer innovators in Kenya and Tanzania (Mutunga et al. 2001; Critchley et al. 1999). For instance, in Mwingi District of Kenya, the conventional way to plant sugarcane is simply to drill the cutting into the riverbed. However, one farmer, Mrs. Lucia Kakundi Kitengu, developed an innovative method of planting sugarcane in pits (figure 3.10). Through her own experiments, she arrived at the optimum design for her farm, which borders a sand river. She would dig holes that were 1 x 1 m square, with depths that range from 0.6 to 0.75 m. The holes are spaced about 0.6 m apart within rows (edge to edge) and 0.6 m between rows. She varies the hole depths according to distance from the stream bank, making holes deeper the further from the river. Thereafter, four sugarcane cuttings are planted in each corner of every pit, and manure is applied. During the rainy season, the holes get flooded, replenishing not only water but also the nutrients. The result is that the sugarcane grows faster, survives the drought better, yields much larger and healthier cane, thereby fetching prices more than triple those on flat areas. This innovation has been copied rapidly by other farmers who have been exposed to the innovation (Thomas and Mati 1999).

Figure 3.10. Utilizing high water table on riverbeds for sugarcane production.



In the Dodoma Region of Tanzania, farmers use the residual moisture from sand riverbeds soon after the rains subside (Lameck, personal communication). They make ridges in the sand while there is still moisture and usually plant sweet potatoes, which take about 3 months to produce tubers, by which time the dry season has started. Unlike in Tanzania, the use of valley bottoms in Kenya has been limited as the Agriculture Act forbids cultivation of riverbeds (Thomas and Mati 1999). This legislation is seen by many farmers as having negative utility, because sand rivers are usually of little use during the dry season, and using them for crop production then would have little impact on soil erosion once the rainy season resumed. This legislation needs to be reviewed.

Spate Irrigation

Floodwater diversion or spate irrigation techniques are those which force the water to leave its natural course, something it would not do without manipulation (Critchley et al. 1992). Spate irrigation, or diversion of flood flow from highlands into lowlands and “wadis”, has a long history in the Horn of Africa, and still forms the livelihood base for rural communities in arid parts of Eritrea and the upper rift valley in Ethiopia (SIWI 2001). Storm-floods are harvested from rainfall-rich highlands, and diverted into leveled basins in the arid lowlands. In Eritrea, the embankments conveying the storm-water can be extremely large (5 m to 10 m high), and are built by shoveling the sandy soil using animal traction. The maintenance of the embankments is very labor intensive, hence it is carried out on a community scale (Negassi et al. 2000).

In the arid and semi-arid areas of Ethiopia, water is an important limiting factor to crop growth (Haile and Tsegaye 2002). Floodwater harvesting has helped convert dry valleys and flood plains into more productive lands, growing a variety of crops such as fruit trees, forage crops and cereals (Critchley et al. 1992). One case study done on agro-pastoral lands in Abaala showed that sorghum and maize are grown in an area receiving rainfall in the range of 300-550 mm/yr.$^{-1}$ This amount of water is obtained annually by diverting rivers through the use of shrubs/trees, stone and soil. The farmers started producing crops following the 1983 to 1985 drought and the subsequent loss of livestock, and also with a view to supplement livestock production whenever there was good rainfall or floods.

In Tanzania, spate irrigation is also practiced in the drought-prone regions of Dodoma, Singida, Tabora, Shinyanga, Arusha and Mwanza. The Smallholder Development Project for Marginal Areas (SDPMA) was an IFAD-funded project in Tanzania that became operational in 1990/1991 (Gallet et al. 1996). The project aimed at improving household food security and incomes of smallholder farmers. It involved smallholder irrigation development based on RWH, strengthening extension services, land survey and registration, and credit. In the first phase (1991-1997), the irrigation development component was designed to establish about 25-30 RWH irrigation-based schemes. About 4,000 ha of marginal lands were planned to be developed for 8,000 farm families (Gallet et al. 1996). The project was able to: 1) construct river diversions and flood protection works for 18 schemes; 2) land leveling and demarcation of 0.5 ha plots for cultivation by individual farm families; and 3) construct access roads. As most of the schemes were being implemented in areas where RWH for paddy production was common, the rate of adoption was high. It was noted that one achievement of the program was the increase in the yield of rice in RWH systems (majaluba) from 1 to 4 t ha^{-1}. However, most of the structures were damaged during the El-Nino rains of 1997/1998. There are major lessons to be learned from what happened during El-Nino rains (Hatibu et al. 2000).

Spate diversion systems have also been practiced in Turkana District of Kenya with good results (Critchley et al. 1992). The diversion (water spreading) schemes consist of earthen embankments that divert part of the flow of wadis into channels, leading the discharge to plains where bunds spread and impound the flow. Some of these schemes are for fodder, and some others are for crops. While there is a considerable range, the schemes are generally expensive (approximately US$ 1,000/ha) to construct and difficult to maintain due to the frequent bund breakages. The different characteristics of each site make engineering design particularly problematic.

Micro-irrigation

Micro-irrigation techniques are gaining popularity among small-scale farmers, especially those using water harvested in tanks and small pans. This is due to the need to make use of limited amounts of water and grow high-value crops or for tree establishment. The most common types of micro-irrigation include bucket drip kits, pitcher pots, bamboo sub-irrigation and bottle-feeding of young tree seedlings.

Bucket Drip Kits

Bucket and drum drip kits are a fast-growing adaptation by smallholder farmers in East Africa, since their introduction to the market in the late 1990s. The most popular and also the cheapest are bucket drip kit systems, which consist two drip lines, each 15-30 m long with emitters spaced about 0.1 to 0.3 m apart, and a 20-litre bucket for holding the water. Each drip line is connected to a filter to remove any impurities that may clog the drip nozzles. The bucket is supported by a stand, with the bottom of the bucket at least one meter above the planting surface. Such a drip kit requires about 40-80 liters of water per day to irrigate about 100 to 200 plants. The most popular crops are high-value vegetables such as tomatoes, cabbage and spinach. Studies by KARI have shown that farmers earned about US$26 to US$40 per season from single bucket kits that cost approximately US$15 in Kenya (Sijali and Okumu 2002; Sijali 2001). However, farmers are confronted with the problem of pests and chickens feeding on their crops, and this is mainly due to such small gardens being the only green areas to be found during the dry season.

Pitcher Irrigation

Pitcher irrigation involves the use of unglazed clay pots, which are buried adjacent to the crop root zone. Such pots are made by women in the traditional way, but the clay is mixed with saw-dust to create porosity when the pot is fired during curing. The pot is filled with water and covered with a clay slab or polythene paper, to reduce evaporation losses. Water seeps slowly through the porous sides of the pot. The minute hairs of nearby plants pull the water out from the pots. The method encourages deeper rooting and reduced evaporation. The method is commonly used for fruit-tree crop production (Vulkasin et al. 1995).

A modification of the pitcher pot by the Kavilo Women’s Group of Machakos District, Kenya involves making clay pots that have small holes punched in the mold. The pot is placed above ground between vegetable crops. The tiny holes can be closed using small sticks, and opened for irrigation when necessary. The advantage is that the farmer has control over the water application. However, there is a limitation of higher discharge rates and also evaporation as water is applied at the soil surface.

Bottle-feeding of Young Tree Seedlings

Bottle-feeding tree seedlings is a water-saving technique for tree establishment in semi-arid areas, which have water scarcity. A bottle is filled with clean water and sealed with a top. A small hole is punched onto the bottle top. The bottle is then inserted into the soil at the tree root zone, ensuring that it lies at an angle. It is a kind of modified drip irrigation in which water enters the soil as small droplets, lasting several days, after which the bottle is refilled. This way, water loss by evaporation is reduced to a minimum (Vukasin et al. 1995).

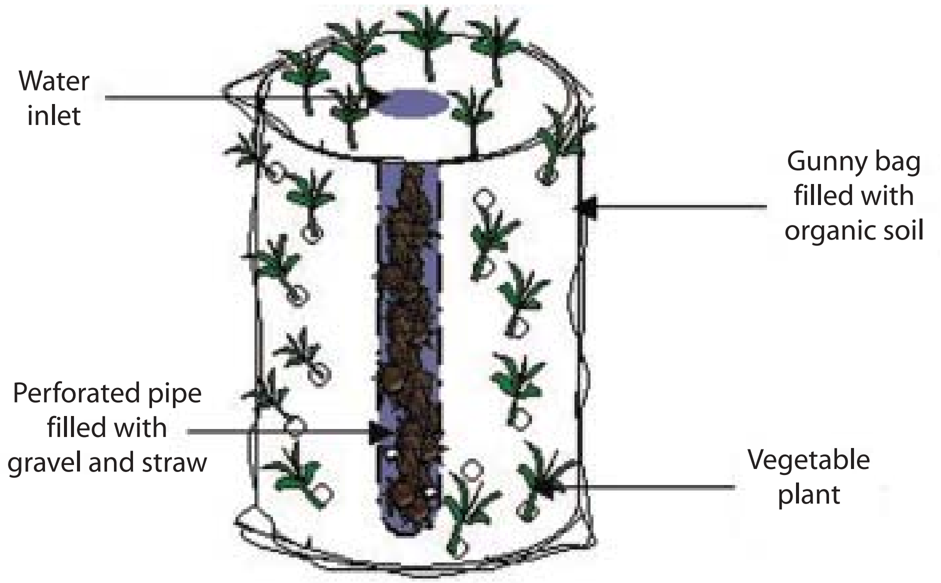
The method is suitable and has been applied in the establishment of forest trees and fruit trees in the dryland districts of Kenya such as Kitui, Machakos, Laikipia and Tharaka. In Budalangi, farmers bury the bottle under the soil to regulate the water temperature and have recorded an increase in tree survival from about 20 percent to almost 100 percent (Bittar 2001). Their trials indicated that white plastic bottles were the best since they do not have a big temperature variation. One liter of water can last for about 2 weeks before refilling. For most trees, this technique need only be applied during the first 2 years of growth when the young tree has not developed a deep root system to extract water from deep soil horizons (Bittar 2001). Using this technique, it has been possible to grow trees in areas where rainfall is received only 2-3 months per a year and, therefore, tree growing without some form of water application is very difficult.

Bag Gardening

Bag gardening is an economical way to grow vegetables as it utilizes air space above the physical limits of the farm, thereby maximizing production where land is a limited resource. The gardens are suitable for both rural and urban areas, including families living in flats. In addition, pests and diseases are fewer and easier to control. In most rural households, bag gardens are used to grow vegetables by utilizing kitchen wastewater, especially where water is really a scarce commodity (Njoroge 1997). Bag gardens come in many shapes and sizes, with the most common type being the utilization of old gunny bags, usually borrowed or bought at a very low price (US$0.10). A typical garden (figure 3.11) is prepared utilizing a used 90 kg jute bag, especially those used in packaging sugar or cereals. Holes are first punched about 2 cm in diameter and at a spacing of 0.25 m-3.0 m starting about 0.15 m from the bottom. The bag is filled with soil that contains about 20 percent well decomposed manure. A watering shaft is created in the soil by placing three posts at the centre of the bag, then packing the space in between with gravel and straw. This shaft acts like a vertical piped sub-irrigation conduit. The garden is watered and vegetable seedlings such as kales, tomato and, spinach are planted through the holes as well as at the top of the bag, which is then covered with mulch. Depending on bag size and crop type, a plant population of 20-50 is possible. The bag garden is kept in the sunshine.

The advantages of a bag garden include intensive utilization of space and scarce water. There is almost no weed control, and damage from pests such as chicken and snails can be avoided by placing the bag on a platform above the ground. Large insect pests can also be avoided by covering the bag with a net. Depending on management, vegetables can grow well for their entire life cycle, which lasts about one year or longer.

Figure 3.11. Typical construction features of a bag garden.



Water Storage Systems

Water harvesting systems with a storage component provide “blue water,” which serves many purposes on a farm, ranging from domestic use, watering livestock and supplemental irrigation. Even though it is common to find micro-dams and farm ponds for storing water in semi-arid areas, they are generally located downstream in watersheds, and the water is predominantly used for livestock and to meet household needs. Farmers in semi-arid areas of Machakos District of Kenya, use earth dams for spot irrigation (with buckets) of small vegetable gardens (less than 0.25 ha) quite commonly (Farmesa 1997). The large water requirements (in general, approximately 1,500 to 3,000 m^3t^{-1} dry matter yield) for crop production also means that earth dams, which generally have a storage capacity of 200 to 1,000 m^3, are used to supplement a crop with water during stress periods and also for small vegetable gardens. Storage systems cover a broad spectrum of techniques, from open surface water storage in micro-dams to retention dams recharging soil water and shallow water tables to sand dams and subsurface dams in sand rivers.

Water storage systems operate at a larger scale than within-field systems, often on a watershed scale, and thereby necessitate addressing issues like ownership, local institutions and land tenure. They require relatively high capital and labor investments (often too high for individual households) and are relatively complicated systems to design. Service-giving institutions, generally, have very little capacity to disseminate and assist in design of storage water harvesting systems (SIWI 2001). In Kenya, there is an institutional conflict, to determine which government ministry is responsible. Earth dams used for irrigation evidently form part of agricultural development, thereby falling under the mandate of the Ministry of Agriculture. But as soon as rainfall is stored in a dam reservoir, it legally becomes a water resource under the Water Act, managed by the Ministry of Water Resources (or similar).

Roof Catchment with Aboveground Tank

Rainwater harvesting from impervious roofs (clay tiles and galvanized iron roofs) is a popular method adopted to secure water for domestic use, because it provides water at home, is affordable, easy to practice regardless of physical or climatic conditions and can be designed to suit different conditions (available finances, roof area, family size etc.,). Since the structure is family owned, maintenance is usually very good and no water conflicts occur. Surface tanks may vary in size from 1 m^3 to more than 40 m^3 for households and up to 100 m^3 or more for schools and hospitals. The tank size is dependent on the rainfall regime and the demand. Areas with seasonal rainfall will require larger tanks (25 m^3 to 35 m^3) and a roof probably exceeding 100 m^2 would be required if total household demand is to be met throughout the dry period. Another benefit of surface tanks (compared to sub-surface tanks) is that water can be extracted easily through a tap just above the base of the tank. If placing it on a stand or base elevates the tank, water can be piped by gravity to where it is required. In addition, construction of such water tanks makes use of locally available materials and local artisans, thus creating employment (Gould and Nissen-Peterssen 1999).

The main reason this technology has not been widely adopted is the relatively high costs involved (by local standards). On average, the per capita daily water requirement in rural areas is 20 liters. Using Kenyan estimates (Mati 2002), the cost of tank construction per capita is about US$150 (equivalent to about US$0.07 per liter) — as a tank can last up to 30 years or more, the investment is considered cost-effective. Another problem has been structural failure, especially of concrete built tanks. Though reasons for this vary, ranging from use of low cement, aggregate mixes, poor quality sand, bad workmanship, poor curing process during construction and generally poor management (e.g., some families drain the tank completely dry). However, when well constructed and maintained, surface tanks provide a durable and long-lasting source of clean water for households, schools and communities. Other than roofs, surface tanks can be constructed below large rock catchments, especially for community water supplies. The water obtained is, generally, of a higher quality than from the conventional boreholes in the ASAL areas. Such tanks should be of a large enough capacity, and the community must be trained in how to manage the catchment and share the water equitably (Mati 2002).

Underground Tanks

Underground tanks offer a cheaper alternative due to its lower construction costs compared to those of surface tanks. They are, especially suited for homesteads having thatched roofs, traditional structures (e.g., Maasai manyattas) and other surfaces, including collection of runoff from paved areas and roads. However, it is necessary to pump (lift) water, except where the ground gradient permits and where gravity outlets are constructed (Cherogony 2000). Another problem is higher possibility of contamination and sedimentation, although the latter can be reduced by providing adequate siltation basins. Perhaps the main problem is the lack of adequate expertise at village level to design and construct underground tanks that do not pose a security risk and are functional. In Machakos District, improved designs of underground tanks (Nega and Kimeu 2002) have seen more farmers adopt them for road runoff harvesting with good results. The underground tanks are preferred in home compounds and are designed as spherical or cylindrical and constructed using bricks. These small tanks (20 to 50 m^3) permit irrigation of small kitchen vegetable gardens, and can be quite cost-effective. In Machakos District, the cost of constructing a cylindrical tank (sausage tank) of 15 m^3 capacity was found to be about Kenya Shillings 15,000 (US$190), equivalent to about one shilling per liter of water harvested (Ngigi 2003). Rectangular and semi-circular plastic lined tanks are also gaining popularity due to the ease of construction, and also the fact that they are more affordable.

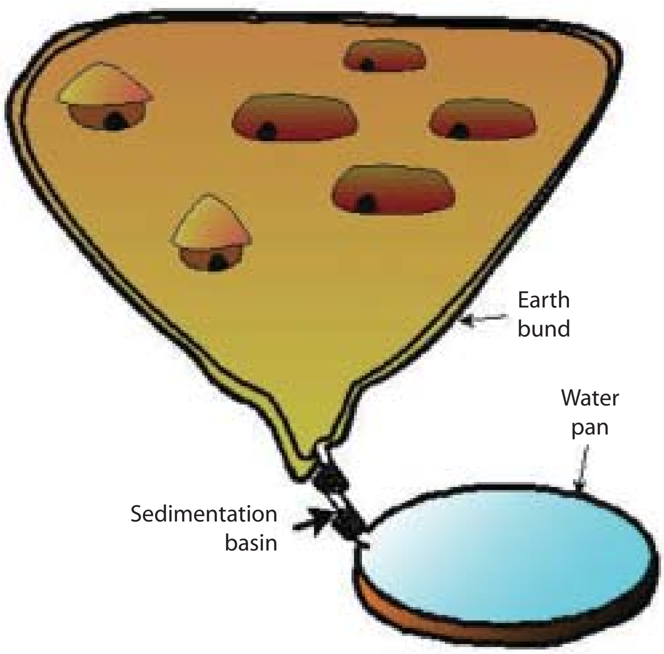
Birkas

In the Somali Region of Ethiopia, underground cisterns, locally known as "birkas," are used for water harvesting (Guleid 2002). Birkas are an indigenous technology and usually family-owned. They are rectangular underground tanks, lined with concrete on impermeable clay tile, mostly for domestic water supplies. In recent years, the Ministry of Water Resources in Ethiopia has been promoting water harvesting through the excavation of underground tanks and pans (Nega and Kimeu 2002). The tanks permit irrigation of small kitchen vegetable gardens (100 to 200 m) and animal watering. The main problem is the heavy labor demand for excavating the pans and making tank foundations. Also, there is the need to pump (lift) water except where the ground gradient permits gravity outlets. There is also the higher possibility of contamination and sedimentation, although the latter can be reduced by providing adequate siltation basins.

Excavated Pans and Ponds

Excavated pans are shallow depressions (1 m-3 m deep) constructed to collect and hold runoff water from various surfaces including from hillsides, roads, rocky areas and open rangelands. Pans have been used for rainwater harvesting in many parts of East Africa, especially for livestock watering. Excavated pans were made popular by "food-for work "programs in the drylands of Kenya and Ethiopia. The pans can be used to collect runoff from the home compound, where houses are grass-thatched or made of cow dung (manyatta) as shown in figure 3.12. When properly designed and with good sedimentation basins, the water collected can be used for livestock watering or to supplement the irrigation of crops.

Figure 3.12. Water harvesting from a rural homestead into an earthen pan.



Problems associated with water pans are: 1) the relatively small capacities; 2) high siltation rates; 3) loss of water through seepage and, 4) high evaporation losses. In an assessment of water resources of Isiolo District, Mati (2003), found that of the 12 operational pans in the district only one provided water throughout the year. In addition, there were high levels of water contamination as most of the pans had not been fenced, which allowed livestock and humans to have direct access to the water in the pans. To control seepage losses, plastic lining of underground tanks and pans has been gaining popularity (Cherogony 2000). However, the high cost of good-quality (dam-plastic) material and the necessity to make-to-measure in large factories in the capital, Nairobi, are major constraints for poor smallholder farmers. Cheaper methods such as clay grouting need to be encouraged, but the problem is usually finding good quality clay material.

Charco Dams

"Charco" dams are really small excavated pits or ponds, which are constructed at well-selected sites on a relatively flat topography for livestock watering (Hatibu et al. 2000). The design is simple and can be implemented at village level with minimum of engineering requirements. For high efficiency in water collection, the pond is situated at the lowest point of the topography. The excavation, achieving depths of 3 m, can be done by machinery or by hand. The right site may be selected using contour maps of the area or by observing where water collects naturally. Charco dams are commonly found in Shinyanga, Dodoma, Arusha, Tabora, Singida and Mwanza regions of Tanzania.

Small Earthen Dams

When larger quantities of water are desired, earthen dams are preferred. An earthen dam is constructed either on-stream or off-stream, where there is a source of large quantities of channel flow. The dam wall is normally 2 m to 5 m high and has a clay core and stone aprons and spillways to discharge excess runoff. Volume of water ranges from hundreds to tens of thousands of cubic meters. Reservoirs with a water volume less than 5,000 m^3 are usually called ponds. Due to the high costs of construction, earthen dams are usually constructed through donor-funded projects. For instance, in the Laikipia District of Kenya, the excavation of an earth dam 15,000 m^3 cost about US$5,000 (Mati 2002). However, there have been cases of smallholder farmers digging earthen dams manually in Mwingi District (Mburu 2000). Earth dams can provide adequate water for irrigation projects as well as for livestock watering. Low earthen dams, called "malambo", are common in the Dodoma, Shinyanga and Pwani regions of Tanzania (Hatibu et al. 2000). It involves dam construction to collect water from less than 20 km^2 for a steep catchment to 70 km^2 for flat catchment. Some of these are medium-scale reservoirs used for urban or irrigation water supply. Sediment traps and delivery wells may help to improve water quality but, as with water from earthen dams, it is usually not suitable for drinking without being subject to treatment.

Hafir Dams

"Hafir" dams are found in East Ethiopia (Guleid 2002). They are either natural or man-made depressions, where runoff water collects, and is used by humans and livestock. Hafirs are, generally, excavated reservoirs with a water volume ranging from 500-10,000 $m^{3.}$ Hafirs are located in natural depressions and the excavated soil is used to form banks around the reservoir to increase its capacity. Bunds and improvements to the catchment apron may help to increase runoff into the reservoir, but seepage and evaporation are often high in the dry season. Hafirs differ from other earthen dams as they are generally bigger in size, and also have good sedimentation basins. Although livestock and people drink directly from earthen dams, in hafirs, watering areas are well allocated, the site is securely fenced and the reservoir is de-silted every season. High water turbidity and sedimentation problems are major drawbacks in eathen dams. And in the case of hafirs the major drawback is the requirement of periodic cleaning to remove silt, which is not an easy task.

Sand and Subsurface Dams

In seasonal rivers in semi-arid areas of East Africa, river profiles usually comprise sand, hence the term "sand river." Sand rivers ("lugga", "wadi", and "khor") are ephemeral water courses, which tend to be dry most of the year (Nissen-Peterssen 2000). However, they are subject to flooding during the rainy season. And during such times if a barrier is constructed across the river the water can be stored in the voids within the sand. The most convenient way to harvest water in a sand river is by either sand or subsurface dams. Local materials for construction are usually available and the only extra cost is that of cement and labor. Local people are usually trained on how to identify a suitable site and in the construction techniques. A case study in Machakos District showed that a sand dam has been successfully used to supply the annual water requirements of a community of 3,000. For instance, subsurface dams in Machakos District of Kenya cost the community about US$0.20-0.30 per m^3 of water (Nissen-Peterssen 2000), but these costs are easily recoverable in the long run. The advantage with sand river storage is that it normally represents an upgrading of a traditional and, hence, socially acceptable water source. Because the water is stored under the sand it is protected from significant evaporation losses and is also less liable to be contaminated. The construction of river intakes and hand-dug wells with hand pumps in the river bank can further help to improve the quality of water.

Nissen-Peterssen (1996) distinguished between three types of subsurface dams: (i) sand dam built of masonry, (ii) subsurface dams built of stone masonry, and (iii) subsurface dams built of clay. Therefore, where deep sand can be found, it is cost- effective to consider the possibility of subsurface sand dams for the storage of the harvested water. A sand dam is a wall constructed across the stream to restrict surface flow. The height of the dam wall is increased by 0.3 m after floods have deposited sand to the level of the spillway. This allows sand to be trapped upstream of the dam wall increasing the overall storage capacity of the riverbed. Sand dams are similar to subsurface dams except that the top of the dam wall exceeds the level of the sandy riverbed. A subsurface dam is where the wall embankment is below the ground. Compacted clay is sometimes used to create the embankment for a subsurface dam. Sometimes the structure is integrated with a drift for river crossing purposes, thereby costing much less. Subsurface and sand dams should be built slowly in stages because if built too high, silt settles in the dam instead of sand. It should go down to the impervious layer below the sand. The water in the sand dam can be reserved for a long time due to low evaporative losses.

Cost Estimates of RWH Interventions

Two important considerations affecting the adoption of RWH technologies are: i) they can be expensive, especially when the systems are water storages such as tanks and reservoirs; and, ii) the low incomes of smallholder farmers. It is for these reasons that most RWH projects have been implemented by funded projects. Even though the costs vary across countries and regions, with the availability of local materials and local operating conditions the basic costs per cubic meter are generally comparable for specified RWH technologies. Examples from rainwater harvesting projects in East Africa, as obtained from published sources (Desta et al. 2005; Nissen-Petersen 2000), expert consultations and experiences of the Southern and Eastern Africa Rainwater Network (SEARNET) are given in table 3.

Table 3. Typical costs for some rainwater harvesting technologies.

Technology	Typical example	Cost	Unit
Underground tanks	Concrete dome-shaped tank	7	US $/m^3
	Brick dome-shaped tank	9 to 14	US $/m^3
	Bottle-shaped tank	4	US $/m^3
	Ferrocement tank	12 to 15	US $/m^3
	Ball-shaped plastic tank	160	US $/m^3
Aboveground tanks	Brick tank	93	US $/m^3
	Ferrocement tank	30 to 70	US $/m^3
	Plastic tank	130	US $/m^3
Runoff open reservoirs	Plastic lined	3	US $/m^3
	Cement lined	5	US $/m^3
	Unlined	100	d/ha
	Lined oval tank	8	US $/m^3
Runoff closed reservoirs	Concrete dome-shaped underground tank	7	US $/m^3
	Brick dome-shaped underground tank	9 to 14	US $/m^3
	Bottle-shaped underground tank	4	US $/m^3
	Ferrocement underground tank	13	US $/m^3
	Hemi spherical underground tank	23	US $/m^3
	Sausage-shaped tank with cement lining	16	US $/m^3
In situ	Human land preparation	113	h/ha
	Draught animal power land preparation	53	h/ha
Sand subsurface dams	Sand dam	0.8	US $/m^3
	Subsurface dam	0.7	US $/m^3
Rock catchments	Open rock dam with stone gutters	71	US $/m^3
	Closed rock dam with stone gutters	89	US $/m^3
	Open rock dam with tank	110	US $/m^3
	Rock catchment tank with stone gutters	46	US $/m^3
	Stone gutters	2	US $/m^3

Source: Desta et al 2005; Nissen-Petersen 2000.

NB: Local materials and labor can be provided by the community

SOIL NUTRIENT MANAGEMENT

Soil Fertility Management

The declining per capita food production in East Africa is associated with declining soil fertility in smallholder farms. This is because nutrient capital is gradually depleted by crop harvest removal, leaching and soil erosion (IFPRI 1996). The use of crop residues by farmers as fodder, and none or shorter fallow periods due to a shrinking land resource base, should be balanced by addition of chemical fertilizers and organic manure, which most smallholder farmers in the region cannot afford. There is, therefore, a need to develop appropriate soil nutrient and cropping systems that minimize the need for chemical fertilizers and also find ways to integrate livestock into the farming system. The focus of any soil fertility replenishment should be integrated nutrient management involving the application of leguminous mulches, agroforestry, composting as well as technologies that reduce the risks of acidification and salinization. Sanchez et al. (1997) suggest that soil fertility replenishment should be considered as an investment in natural resource capital. Studies by Murage et al. (2000) show that soil fertility depletion results from an imbalance between nutrient inputs, harvest removals and other losses, and that it is reaching critical levels among smallholders in East Africa (with depletion of soil organic matter being a contributory factor). For example, Smaling et al. (1993) estimate that 112, 2.5 and 70 kg ha-1 per year of nitrogen, phosphorus and potassium respectively, are lost from agricultural soil in Kenya. In many small-scale farms, crop residues are harvested and fed to livestock, and very little is returned to the soil to replenish lost nutrients. The depletion of organic matter thus exacerbates this condition.

The concept of “poor” and “fertile” soil may mean different things to different communities and conditions. Soil fertility refers to the capacity of soil to produce crops by providing adequate supply of nutrients in correct proportions, resulting in sustained high crop yields. In addition, a fertile soil has good rooting depth, good aeration and good water holding capacity. It is also necessary that there is a strong presence of soil organisms, e.g., earthworms, adequate amounts of organic matter, the right pH balance and no adverse soil-borne pests and diseases (Landon 1991; Njoroge 1994). Efficient farm management practices should result in greater stimulation of activities of soil organisms, nutrient additions to the soil, minimal nutrient exports from the soil and optimal nutrient recycling within the farming system (Landon 1991; Young 1976). Therefore, it should be possible to say accurately whether a soil is fertile or not, based on well-defined criteria.

In the subhumid highlands of Kenya, soil fertility management among smallholder farmers is quite widespread. For instance, in Embu District, 99 percent of farmers use mineral fertilizers, 91 percent use farmyard manure and 74 percent do crop rotations, while in Vihiga, western Kenya, 75 percent use compost manure, 79 percent use green manure and cover crops, 91 percent use farmyard manure and 93 percent use crop residues (Amudavi 2005). Other soil fertility-enhancing interventions include improved fallows, biomass transfer and crop residues. In soil and water management, technologies that improve soil fertility and productivity are as important as those that reduce erosion and loss of water. These include practices such as residue mulching, contour tillage and tied ridging, minimum tillage, subsoiling, crop rotation, cover cropping, rotational grazing, contour ripping and direct application of organic matter, farmyard manure and inorganic fertilizers.

Use of Mineral Fertilizers

The use of mineral fertilizers in East Africa, though not a traditional practice, has been catching on quite well, albeit with low application rates. In Ethiopia, fertilizer use trials have been done with farmer experimentation in Galessa and Meta Robi districts, in Welmera and Ilala Gojo areas near Holetta (Sinebo et al. 2002; Agegnehu 2002; Aregu, et al. 2002) and in many other areas as well for wheat, pea, barley and teff. The response of crops to fertilizer has been good, showing great otential for increasing crop production. However, the cost of fertilizers is beyond the reach of poor farmers, nevertheless this practice has become popular among wealthier farmers. A study in 1995 (Eyasu 2002) revealed that 78 percent of the farmers interviewed used mineral fertilizers and virtually all the nonusers were poorer farmers. The major type of fertilizer used was DAP. The quantity of fertilizer used depends on the socioeconomic level of the farmers, with richer farmers using more fertilizers. Field trials on maize and sorghum with and without fertilizer application in the semi-arid areas of eastern Ethiopia showed that a substantial yield increase occurred when fertilizers were used along with water conservation practices. However, over 50 percent of the increase in yield was attributed to water conservation (Eyasu 2002).

In Kenya, the use of mineral fertilizers has been common among smallholder farmers for commercial crops such as coffee, tea and tobacco, but their use has been very low for food crops. The mean application rates are about 35kg ha^{-1} (World Bank 2003), which is below the basic requirement for most types of soil. Although the application rates for cash crops are closer to the recommended level the application rates for food crops are way below the required level. Even though expensive, the use of inorganic fertilizers needs to be promoted, as many types of soil lack adequate levels of phosphorus and nitrogen. Mati and Mutunga (2005) observed that farmers were not using fertilizers in Kusa, Nyando District of Kenya, partly because they were not available locally, and that the nearest shop where fertilizers could be obtained was over 40 km away. They (Mati and Mutunga 2005) recommended that farmers be trained in using fertilizers suitable to their requirements and the proper methods of application. It was also suggested that modalities be found to bring fertilizers closer to the people through local shops, and packing them in small quantities to ensure affordability. Most farmers know only of DAP, and as such, there is a need to educate them on the differences and uses of various fertilizers, why application is necessary, appropriate timing of application and the rates of application. In addition, farmer experimentation should be encouraged.

Use of Organic Manure

Levels of organic carbon have been shown to be the overriding factor affecting soil fertility. Murage et al. (2000) observed that among soil organic pools and fractions, total organic C was the most sensitive soil quality indicator, suggesting that within a narrow range of soil it may serve as a suitable indicator of soil quality. Other studies in Kenya (Irungu et al. 1996; Kapkiyai et al. 1998) report that soil organic matter fractionation may offer insight into soil fertility changes and the sustainability of past management systems. The use of organic manure in Ethiopia is constrained by shortage of organic materials such as crop straws and animal dung. Many smallholder farmers feed crop residues to livestock and the manure is dried and used as fuel. Thus, nutrients are not returned to the soil (soil mining) leading to declining soil fertility, reduced soil moisture retention and ultimately poor yields (Tefera et al. 2002). Owing to declining holding-size, farmers in many high potential areas have resorted to continuous cultivation, thereby further exacerbating land degradation and poor crop production.

With farmers keeping small ruminants, the need to diversify the sources of manure has grown. Farmers keeping goats use "goat manure" with good results. Experiments at Kibos, near Kisumu in Kenya (Onim et al. 1990) showed that goat manure had superior soil fertility impacts when compared with DAP fertilizers, which is popular among farmers in Kenya, despite its relatively high pH. Moreover, goat manure is more economical and it has low direct costs. The use of manure has been growing as a result of farmers getting more sensitized, especially with conservation technologies. The main problem, however, has been the decline in the quality of manure, which is attributed to substandard storage facilities and irresponsible handling.

Green Mulches/Manure

Green mulches are usually leguminous plants that cover the ground as runners, grown together with other crops. They are sometimes also termed as green manure because of the ability of the companion legume to fix nitrogen in the soil. The legume could be cut and incorporated into the soil while green as manure. Alternatively the legume is used as a cover crop. Other types of crops such as pumpkins and water melons have proved useful green mulches. The author found that in a papaya plantation in Embu District of Kenya, the use of water melons as a companion crop improved soil moisture conservation. Trials by farmer experimenters in Mbozi District, southern Tanzania (Hilhorst and Toulmin 2000; Thomas and Mati 2000) showed that by planting velvet bean under coffee the weeds were reduced (smothered by the cover of the bean), while the coffee yield increased due to water conservation and soil fertility improvement, as a result of nitrogen fixation by the beans.

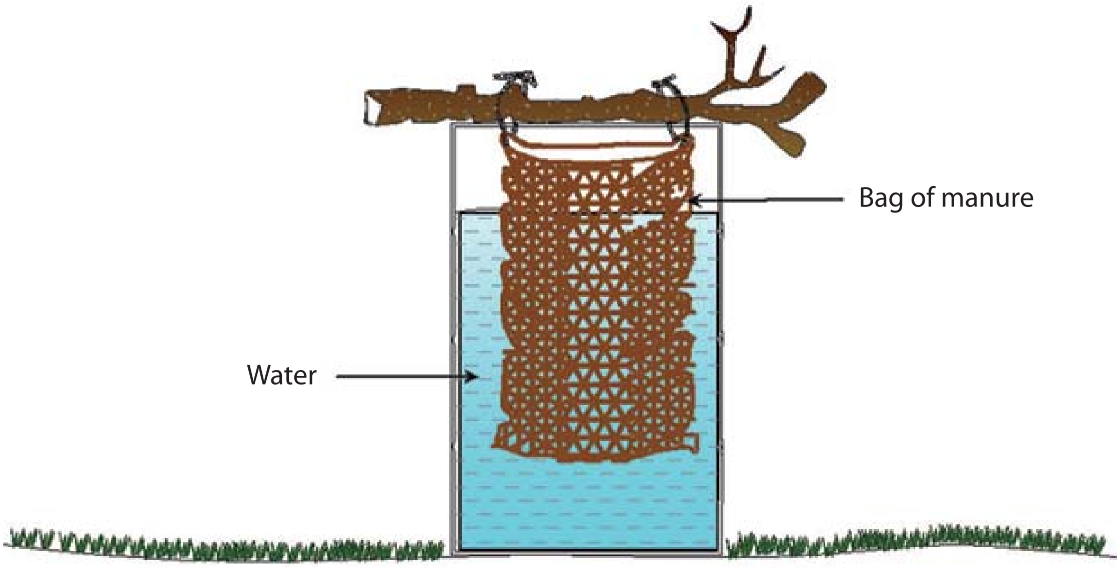
Plant Teas

Occasionally, liquid manure is prepared in the form of "plant tea." Plant teas are especially necessary to quickly provide the crop with adequate natural plant food during the growing season, and as a top dressing. In preparation, plant teas utilize green sappy leaves and young branches of leguminous trees, which are chopped and put in a drum of clean water (figure 4.1). The drum is covered and left to stand. Depending on type of plant material used and the temperature, the plant tea is ready for use within two to three weeks. It is then diluted at least by 1:2 parts per volume before application (Njoroge 1994).

Composting

Composting is gaining importance, especially among smallholder farmers, particularly with those who are more progressive and innovative. Composting is the natural process of turning organic materials, such as crop residues and farmyard manure, into valuable plant food or humus (Njoroge 1994). The ingredients that produce good quality compost, such as leguminous residues and manure, are just as important as the methodology of composting. Composting has been one of the most common features among farmer innovators in East Africa (Kibwana 2000; Critchley et al. 1999; Reij and Waters-Bayer 2001) and farmers involved in organic farming (Thomas 1997). The normal procedure in composting is to first make a foundation onto which ashes are spread to prevent termite infestation. Then layer after layer of dry crop residues (chopped), green vegetation e.g., *Lantana camara* and *Tithonia diversifolia* and topsoil are placed over each other, wetting with

Figure 4.1. Illustration of the preparation of plant tea.



fresh water (non-chlorinated). The heap is then covered with soil and a stick driven into the middle to act as a thermometer. The compost is turned (and wetted) after around 22 days. In most parts of East Africa, the compost is ready for use within 45 days (Njoroge 1997).

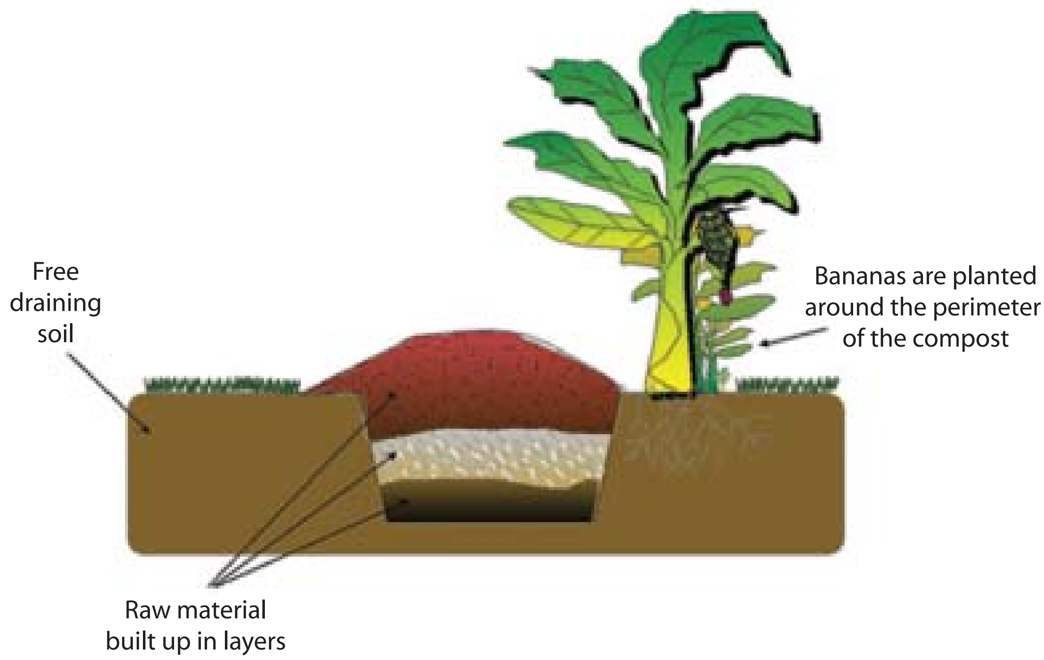
Mapambano Compost Making

"Mapambano" compost making is an innovation by farmer, Ms Susanna Sylvesta of Dodoma, Tanzania (Mutunga and Critchley, 2001). She makes 15 tons of compost each year. The composting system is based on locally available materials and pits of over 1 m deep and up to 3 m in diameter. Ash is spread at the bottom of the pit, and then a layer of grass is added, followed by alternating layers of crop residues, grass, tree leaves, sisal leaves, manure, bedding, animal urine and ash. Domestic wastewater is added to keep the mixture moist. The pit is filled (built above ground level) and topped off with a final layer of ash and a cap of grass. Wastewater and urine continue to be added to keep it moist until it is fully decomposed. This takes about 3 months and produces a rich compost, which is applied to the maize crop at the rate of 1.5 t/ha/year. There were plans to package the compost for sale even in the export market (Lameck personal communication).

Compost Baskets

Another system of composting known as "compost baskets" is also common in various parts of East Africa (Hamilton 1997). The idea of a compost basket is to do *in-situ* composting in which the crop utilizes the compost as it decomposes, and thus is expected to last longer (figure 4.2). Compost baskets are woven from twigs and driven into the prepared beds at a spacing of 1 m as follows: holes of at least 15 cm deep and 30 cm wide are dug along the centre line of the prepared bed at a spacing of about 1 m. Sticks of about 60 cm long are then driven into the ground around each hole, and long flexible twigs woven around to form aboveground baskets. The baskets are filled with manure and well-decomposed household wastes. The manure is translated from the soil below the basket into the root zone through natural processes. Due to hydrotropism the roots also tend to grow towards the basket. This technique has been tried in Funyula division of western Kenya for tomato production. Yields recorded indicated a production value of Ksh 100 (about US$1.40) per square meter of land (Bittar 2001). In eastern Kenya, KIOF has popularized the use of compost baskets, which farmers have found requires less labor than normal composting.

Figure 4.2. Compost basket with a banana plant.



Double-dug Beds

Double-dug beds (DDBs) are made to prepare the soil for cultivation by breaking the soil in the hard pans and creating a deep layer of loose soil that is fertile (figure 4.2). This practice aerates the soil, improves water absorption and retention, allows plants to use available nutrients more efficiently and increases rooting depth (Njoroge 1994; Hilhorst and Muchena 2000). These beds can be used for intensive cultivation and will produce higher yields than in shallow tillage. Commonly recommended dimensions of a double-dug bed are approximately 1.5 x 7m wide and 60 cm deep. The bed is filled with about six wheelbarrows of compost, which can be used for four consecutive cropping seasons before the process needs repeating. Farmers have adapted this method in various ways, digging less deeply when the soil is rocky or when labor is scarce, changing the length of the beds and adding a variety of organic materials. Composting and DDB seem more widely used in higher areas than in medium potential areas. This may be due to two reasons: 1) water is more easily available in high potential areas; and, 2) manure can be readily obtained from zero-grazing units. Tests, however, show that DDB and composting produce higher yields of maize, better gross margins and returns to labor in a medium potential area such as Machakos when compared to high potential Nyeri District of Kenya. This is probably because hard pans are more frequent in Machakos (Hilhorst and Muchena 2000).

Double-dug beds have been promoted by NGOs since the late 1980s in Ethiopia, Tanzania and Kenya, where they are mainly used for cultivating high-value cash crops such as vegetables (Hamilton 1997). The construction technique involves preparing the garden beds by digging out the topsoil and subsoil separately. The bottom of the trench is further tilled to improve infiltration. The topsoil is then mixed with organic manure and returned to the bed. Care is taken not to step on the bed in order to avoid compaction. High-value crops are then grown on the beds with very good results since the bed absorbs more water than in conventional tillage. Their adoption and subsequent adaptation are closely linked to increased production of compost, which should be added when the double-dug beds are prepared. As found in a survey, 22 percent of farmers who had been trained in Low External Input Sustainable Agriculture farming technologies used double-dug beds. (Thomas and Mati 2000).

Mulching

The objective of mulching is to conserve soil moisture, reduce runoff flows, evaporative losses and wind erosion, prevent weed growth, enhance soil structure and control soil temperature. Mulching in East Africa normally utilizes natural materials and involves covering the soil with cut grass, crop residues, straw or other plant material. In East Africa, mulching is practiced by farmers in the wetter areas due to the availability of vegetative materials. Most smallholders do mulching only for special crops such as tomato, cabbage and potatoes due to the shortage of crop residues. Depending on availability of residues, mulch densities range between 30 percent and 70 percent, based on availability of residues obtained from the previous season’s crop (Kibwana 2000; Mruma and Temu 1999). The importance of mulches in reducing surface runoff, soil erosion and evaporation losses cannot be overstated. In an experiment in the Laikipia District of Kenya, it was observed that in the absence of mulch, 40-60 percent of the rain that fell was lost to evaporation, and that if 40-50 percent of the ground was covered with mulch, surface runoff losses were reduced to almost zero and evaporation losses halved (Liniger 1991). Crop yields were found to double or triple and biomass to feed the livestock increased. In a participatory experiment with farmer innovators in Mbozi District, Tanzania, the Indigenous Soil and Water Conservation Program (ISWCP)—(Kibwana 2000; Mruma and Temu 1999) tested the use of crop residues to mulch the coffee crop grown in the marginal Mbozi District. The farmers found that coffee yield nearly doubled under the mulched plots, a factor that was associated with soil moisture conservation.

Agroforestry

Agroforestry, though an indigenous intervention among many communities in East Africa, gained its prominence in the 1980s after the establishment of the International Council for Research in Agroforestry (ICRAF, now called “World Agroforestry Center”), which set up office in Nairobi with field activities in the region. In Kenya, Ethiopia and Tanzania, seedling production was taken up as a component within the SIDA-supported Soil and Water Conservation Project (SWCP) of the respective Ministries of Agriculture. The initial focus was on the nurseries, but from 1988, there was a shift towards a more holistic and supportive role in recognition of the need to work in a participatory manner with farmers. More emphasis was put on farmers’ training rather than production of seedlings. Production of information material for extension staff, farmers and schools became an important component (Muturi 1999). Enthusiasm for farm forestry activities increased in response to the prevailing political push and intensification of extension. A variety of institutions became involved in seedling production. They included government ministries, nongovernmental organizations (NGOs), rural development projects, farmer groups and rural communities. By mid-1991 there were 4,161 documented tree seedling nurseries established by various institutions in Kenya alone (Muturi 1999), while soil and water conservation projects in Ethiopia and Tanzania all had a strong agroforestry component (Lundgren and Taylor 1993; Assmo and Eriksson 1994).

A majority of the smallholder farmers practicing agroforestry prefer to grow multipurpose trees. They have realized that through agroforestry trees provide nutrient inputs to crops by capturing nutrients from atmospheric deposition, biological nitrogen fixation, tapping nutrients from deep in the subsoil and storing them in the bio-mass (Sanchez et al. 1997). Trees also enhance nutrient cycling through conversion of soil organic matter into available nutrients (especially nitrogen and phosphorus). It is, therefore, possible to recycle nutrients through leaf-fall, root decay and green manure (Biamah and Rockström 2000). Agroforestry also benefits farmers directly through the provision of poles for building, fruits for sale and consumption, fuel wood and fodder for livestock. The trees also prevent soil erosion, conserve soil water and improve soil fertility and the micro climate. The environmental benefits of trees include soil conservation, bio-diversity conservation and the conservation of terrestrial carbon.

Hedgerow Intercropping

Hedgerow intercropping or alley cropping was popularized by ICRAF in the 1980s, but adoption by farmers has been poor. It involves growing leguminous tree shrubs in narrow strips across the slope, then the shrubs are lopped and the material used as a green mulch. Popular species include *sesbania sesban*, *caliandra calothyrsus* and *leucena sp* (Thomas 1997). Nitrogen fixation by the hedge roots and its incorporation through pruning is supposed to replace the need for nitrogen fertilizers thus saving costs. However, competition for moisture between crop and hedges was a major limitation factor in the dry areas. With the exception of the aforesaid problem, hedgerow intercropping can be quite effective in soil conservation as explained below.

ICRAF tested low hedgerows of *Cassia siamea*, a leguminous and nitrogen-fixing shrub, planted on the contours to enable the development of natural formation of terraces on a 14 percent land slope at Katumani, Machakos (Lundgren and Taylor 1993). One night in April 1990, 52 mm of rain fell in just 30 minutes on slopes that were already saturated. Fields with only crops lost more than 34 tons of soil per hectare. , while fields with hedgerows lost, at most, 6 tons per hectare. Where maize and cowpeas were grown between hedgerows the produce was two to three times the harvests from fields with sole crops. (Lundgren and Taylor 1993).

Improved Fallows and Biomass Transfers

Improved fallows have been described (Sanchez 1999) as the deliberate planting of leguminous tree species with the primary purpose of fixing nitrogen as part of a crop fallow. Improved fallows have been introduced more recently in the Lake Victoria region where agroforestry techniques form a major focus on soil fertility initiatives, to enable the enrichment of a natural fallow with leguminous trees or shrubs (Place et al. 2005; Woomer et al. 2004). These shrubs include *Sesbania sesban*, *Crotalaria grahamiana* and *Tephrosia vogelii*.

Another system, biomass transfer (Nair 1989) is the incorporation into the soil of leafy shrubs, which accumulate high concentration of nutrients in their leafy biomass and mineralize rapidly. It is a form of cut and carry mulching, and shrubs such as *Lantana camara* and *Tithonia diversifolia* are used in this system. In western Kenya, *Tithonia diversifolia* is the most commonly used biomass material because it is readily available, easy to propagate and relatively richer in nutrients. One ton of dry weight of *Tithonia diversifolia* leaves contains an average of 33 kg of nitrogen, 3.1 kg of phosphorous and 30.8 kg of potassium (Mureithi et al. 2002).

Low External-input Farming Systems

There are different synonyms used to describe low-input farming technologies which include Alternative Agriculture, Low-Cost External Input Agriculture, Bio-Intensive Agriculture, Sustainable Agriculture and "Permaculture" or LEISA (Low External Input Sustainable Agriculture). In its most extreme form, low-input agriculture is known as organic farming. Organic farming has been defined (Njoroge 1994) as an agricultural system that promotes environmentally sound means of production. Organic farming uses natural methods to keep the soil fertile and also keep crops and livestock healthy. The approach keeps the land productive using materials found on the farm. In conventional farming systems, much effort goes into to bringing chemical inputs and animal feeds from outside the farm, instead of making full use of what is found on the farm. For example, expensive inorganic fertilizers, sprays, vaccines and medicines are used. With the compaction of soil as a result of using heavy machinery more fertilizers and pesticides are required to increase the yield. Owing to the inherent weaknesses of artificially-fed plants, new pests and diseases are emerging all the time and even others commonly found become resistant to pesticides, while beneficial soil organisms get killed. In contrast, the organic farmer puts effort into improving soil fertility through composting, proper cultivation, rotation of crops, mixed planting, growing trees, proper care of crops and animals and the natural control of pests and diseases. Because of the better natural balance, agricultural products are healthier and fetch a much higher price than conventionally grown crops and, in general, ensure good health and environmental safety all around. In East Africa, most farmer innovators practice a certain degree of low-external input agriculture, which is necessary to reduce costs of production and the dependence on "imported" inputs and also to ensure sustainability of the ecosystem.

PARTICIPATORY APPROACHES IN WATER AND NUTRIENT MANAGEMENT

An approach is the essence of an agricultural research and extension program, comprising an organizational structure, leadership, resources such as personnel, equipment and facilities, goals and objectives as well as methods and techniques for implementation. It also has linkages with other organizations, the public as well as its clients, i.e., partners and/or collaborators (Ejigu 1999). It is argued that over the three decades ending in 1990, millions in foreign exchange have been spent on research and extension approaches in Africa, aimed at promoting agricultural development. However, even this expenditure has been ineffective in stimulating growth and alleviating poverty and human suffering. The problem lies both with national policies and donor perceptions (Lele 1999). To promote research development in Africa, many initiatives have been introduced. For instance, the East Africa Framework for Action on Agricultural Research was developed (Kampen 1992), with a mandate to identify measures required to improve the performance and effectiveness of agricultural research in the region. This resulted in the formation of the Special Program for African Agricultural Research (SPAAR), which was able to get the support of national policymakers and donors. In addition, obtaining the support of other institutions involved in technology generation and dissemination was important for the success of the measures identified in the framework for action. Even with such initiatives, agricultural research and extension approaches have been underutilized in East Africa, for many reasons.

Towards Recognizing Farmer Knowledge

The East Africa region has seen many experimentations in agricultural and natural resource management involving technologies, policies, research and extension packages (McCall 1994; Tengberg et al. 1998; de Waal et al. 1997; Kiome and Stocking 1995; Critchley et al. 1994). The analyses of the successes and failures of rural extension approaches have revealed that transfer of technology approaches which assumed a one-way stream of knowledge, from research to extension to farmer, have been ineffective (Schwartz and Kampen 1992). These approaches ignored the knowledge already existing in communities and failed to recognize the processes by which farmers learn and adopt new practices. Efforts to achieve a more systematic involvement of resource poor farmers through public sector agricultural research organizations have been weak. This is due to the lack of internal motivation on the part of the scientific researchers, and also because of the lack of external pressure from the farmers (Lacy 1996). Rarely do farmers demand research services from researchers. To bring about more effective functioning of the system, several models have emerged that describe the relationship between scientists/researchers, extension educators, farmers and the informal sector. These have been described in different terms such as on-farm research, farming systems, agro-ecological research, rapid and participatory rural appraisal, farmer participatory methods and farmer field schools (Norman et al. 1994; Chambers et al. 1989; Haile and Lemma 2000; Duveskog 2001). The fact that farmers themselves can contribute towards new technologies in land husbandry and the role of indigenous technologies in soil and water management as a way to improve farmer-researcher-extension linkages are being given more credence (Reij and Waters-Bayer 2001; Bittar 2001; Abbay et al. 2000; Haile 2000; Critchley et al. 1999). Innovative and indigenous ways of achieving improved yields have involved a wide diversity of interventions such as integrated soil fertility management, soil and water conservation, rainwater and runoff harvesting systems, integrated pest management, tillage and soil management systems, improved seeds, innovative agronomic practices and better ways of scaling-out successful practices (Ndakidemi et al. 1999; Ochola et al. 2000; Wolde-Aregay 1996). However, these success cases are few and far between.

Indigenous Technologies and Knowledge

Indigenous knowledge has been defined (Mwale and Mruma 1999), as *"a mixture of knowledge created endogenously within a society and knowledge acquired from outside, but observed and integrated within the society*". Therefore, indigenous knowledge is area-specific, originates from farmers themselves and solves specific problems at a particular time (Scarborough et al. 1997; Evers 1995). On the other hand, indigenous technologies and knowledge (ITK) is best described in terms of four categories (McCall 1994): (i) the vernacular technical knowledge held by local people, (ii) specialized knowledge of certain skilled "Resource Persons," (iii) the controlling knowledge held by dominant groups in society, and (iv) the social knowledge belonging to the group (village, clan, caste, tribes etc.,). Local knowledge is a resource because it may be the only thing that the poorest people have a control of. It should reflect the capability and competence of the local community and put them on an equal footing with outsiders, and it is a resource needing little investment for realization. Moreover, local knowledge is operational and measurable. ITK can be identified and interpreted through: (i) rapid rural appraisals; (ii) participatory action research; (iii) field survey approaches, including interviews and field measurement; (iv) farming systems research, including agroforestry diagnostics and design; and, (v) gaming and similar techniques.

Participatory Technology Development (PTD)

Participatory Technology Development (PTD**)** has been seen as a more effective way to enhance farmer-extension-researcher interaction. PTD refers to the collaboration between farmers, development agents and scientists in a manner that combines their knowledge and skills (van Veldhuizen et al. 1997). One important component of PTD is farmer-led experimentation, to find better ways of using available resources to improve the well-being of families and communities. The purpose of supporting farmer experimentation is to strengthen farmers' capacities to seek and try out new ideas so that they are better able to experiment and adjust to changing conditions. The purpose is not to convince farmers to adopt a new technology, but rather to encourage them to test new possibilities and choose what is right for their circumstances or adapt the new ideas to their conditions. The PTD approach is linked to the concepts and methods of sustainable forms of agriculture that rely mainly on locally available resources and do not require major inputs from outside (Kibwana 2000). The PTD approach aims to identify and where possible improve or adapt those technologies to meet the current needs. In promoting PTD, use of the subsidy mechanisms and genuine demonstration of technology are necessary to avoid promoting ideas that will be of no interest to the farmers. It should have well-coordinated land-use planning, including farming system approaches, addressing the diversity of ground realities and avoiding straight-jacket formulae. It is important to make a good investment in infrastructure for scientific data collection to facilitate decision-making on a more reliable scientific basis. Emphasis on development, maintenance and efficient management of community assets such as dams and community lands is important, but at the same time the need to decentralize the process of decision-making with a view to empower local communities should be also given due recognition. A coordinated action by all the stakeholders in the farming sector, including the government is vital (Virman et al. 1995).

Scaling Up and Scaling Out

Technology transfer is nowadays seen to be not just bottom-up, or top-down, but rather circumferential and indeed in all directions. Such terms as "scaling up," "scaling down," and "scaling out" have been used, sometimes interchangeably. The GFAR (1999) defined these terms in a stakeholders' forum, and discussed the principles and practices associated with each term. For instance, "scaling up" was defined (GFAR 1999) as the vertical movement of experience, knowledge, impact and effects higher up the levels in the organization of a sector or society. This implies moving more stakeholder groups up the ladder from farmers to "extensionists" and NGO workers to local officials to researchers to policymakers/ministers to donors. On the other hand, "scaling out" is a horizontal spread within a sector, particularly farmers. Both scaling up and scaling out implies adaptation, modification and improvement (not just replication) of particular technologies and techniques, but more importantly principles and processes**.** "Scaling down" refers to the replication of whole programs, not just principles or processes, by breaking them down into smaller programs or projects to facilitate planning, implementation and accountability at lower levels. It may be viewed as decentralization or devolution and, therefore, one could equate these processes with scaling out as well. The GFAR (1999) listed five dimensions of scaling up: (i) the institutional (vertical integration); (ii) the geographical/spatial (horizontal spread); (iii) the technological; (iv) the temporal; and (v) the economic or cost dimensions. In all, sustainability, "participation" and "capacity building" are common themes. In addition, there are three general strategies adopted by an implementing organization in dealing with the issue of scaling up relative to how it conceptualizes its project/program intervention: (i) spontaneous scaling up; (ii) scaling up after achieving initial local success; and (iii) inclusion of the scaling up plan right from the start of the project.

In terms of the approaches and principles that would guide an organization in implementing its scaling up programs, the GFAR (1999) proposed eight general categories. These were: (i) action research and learning; (ii) human relationship building; (iii) local capacity building and resource mobilization; (iv) market development; (v) participation; (vi) policy change and development; (vii) strategic alliances; and (viii) training and extension. Although there is a wide range of tools, approaches and principles, the process of up-scaling remains a difficult task.

Cooper and Denning (1999) provide a model for scaling up agroforestry research and extension, as shown in figure 5.1. They indicate that sustainable development takes place within the context of many external factors over which research and development partners may exert little influence, if any. Even so, when designing development initiatives, there is a need to be aware of the positive and/or negative influences such factors can have, and plan accordingly. The following conditions are necessary preconditions for scaling up/out:

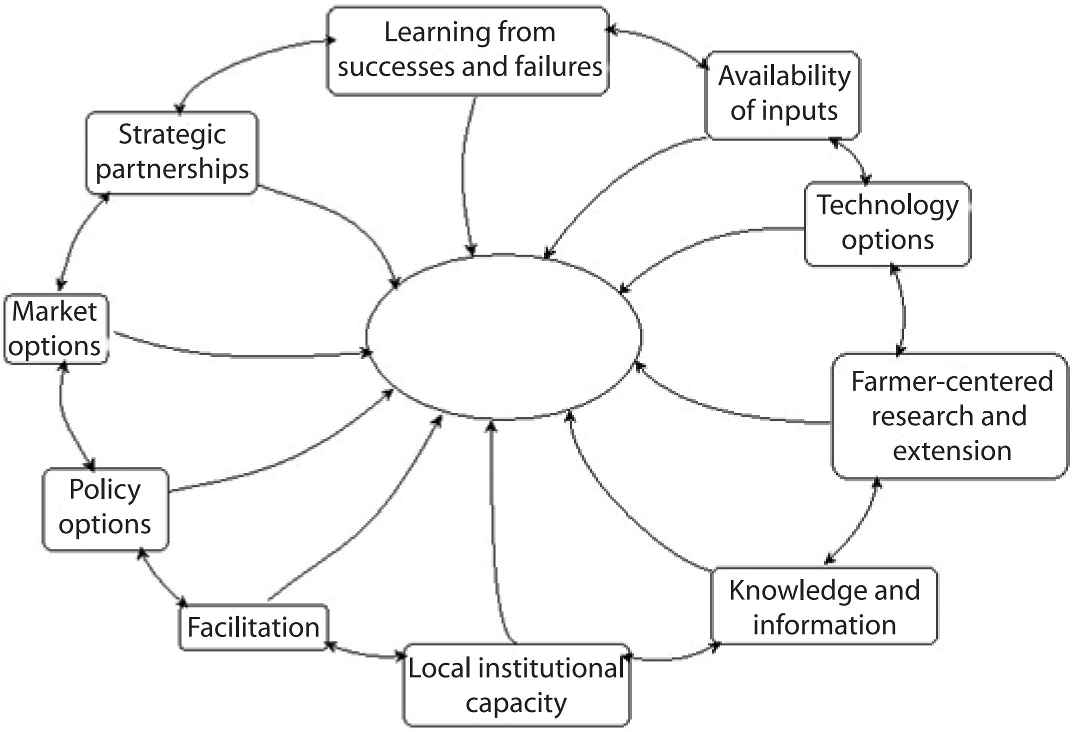
- i National and regional peace and security;
- ii Good and transparent governance;
- iii Demand for products and market access;
- iv Sound national and global economies;
- v Legislation in place covering intellectual property rights;
- vi An active process of democratization;

vii Functional rural infrastructure;

viii Decentralization of decision-making; and

ix Resource availability.

Figure 5.1. Scaling up innovations (Adapted from Cooper and Denning 1999).



The Role of NGOs

In recent years, NGOs (Nongovernmental Organizations) have played an important role in participatory research and extension. NGOs bridge the gap in community development and have contributed to resource mobilization, capacity building, changing community attitudes and saving lives in relief support (IIRR 1998; Dagnew 2000). Some NGOs, especially in disaster prone areas, have shown strong commitment by addressing issues such as food deficit, gender, problems of rural women, HIV/AIDS, supply of water to rural areas, savings and credit as well as participatory planning and management. Most NGO projects are backed by relatively better monitoring and follow-up arrangements; and they are good at playing advocacy roles, mobilizing external resources and often have the capabilities to reach the grassroots communities. NGOs in addition to providing employment opportunities are operationally less bureaucratic and more flexible.

Despite these achievements, NGOs have inherent weaknesses as they tend to be operationally expensive and resource insensitive, and have a tendency not to comply with existing norms and regulations. Most indigenous NGOs find it hard to raise funds locally, and therefore, have become much dependent on external funding. Lack of clear understanding of government policy and being less results-based are drawbacks that can have a negative impact on the performance of NGOs. Farrington and Bobbington (1992) compared the roles of NGOs and government organizations (GOs), and found that GOs and NGOs can complement each other in dealing with farmers. For instance, GO and NGO staff can jointly participate in training courses, especially in action-oriented methods such as PRAs, collaborative field trials and information exchange. In addition, GOs can cushion NGOs with budgetary allocations for some specific tasks, while NGOs can act as brokers between farmers and research services and donors.

The list of NGOs that have been active in agricultural training, extension and/or research in East Africa is long and, as such, only a sample is presented here. In Ethiopia they include: Agriservice, Action Aid, Farm Africa, Catholic Relief Services, World Vision, Water Action, Sasakawa 2000, IFOAM, Christian Relief and Development Association and CARE. In Tanzania, they include: Inades-Formation, TIPDO; Catholic Relief Services, Anglican Church, Habitat for Humanity, Relief and Development Services Association (REDESA), Centro Mondialita Sviluppo Reciproco, Water Aid, Dodoma Environmental Network (DONET), Agrisystems and Action-Aid. In Kenya, they include: Catholic Relief Services, Anglican Church of Kenya, Plan International, Action-Aid, Freedom From Hunger, CARE-Kenya, World Vision, Caritas, Approtech, ALIN, SoS Sahel International (MDFP), KIOF, Africa-Now, Resource Projects Kenya, Ramati, Osienala and SACRED-Africa.

Farmer Organizations and Networks

Farmer organizations have played a leading role in the development of agriculture in East Africa. Cooperative societies have, more than any other farmer support institution, influenced agricultural commercialization among small-scale farmers (Dejene 1989). Cooperative societies are important in relation to commodity marketing, supply of inputs, provision of credit and among other similar functions. The effectiveness of a cooperative society depends on its level of development. On the one hand there are the budding cooperative societies that do not have any fixed assets and, whose members are not aware of their rights, obligations and benefits accruing from membership, and the society leadership has no business experience. On the other hand, there are the cooperative societies that are well developed, do not require external support, well managed, able to provide credit to their members, invest in agro-processing and venture into export-import business, (Muturi 2001).

A network is any group of individuals and/or organizations that on a voluntary basis exchange information or goods or implement joint activities and organize themselves in such a way that the individual autonomy remains intact. Networks can have different forms and use different procedures depending on the specific situation. The networks structure is often light and not very formal. Many development projects are nowadays promoted and implemented through networks (Njoroge 1997; Hatibu et al. 2000). In East Africa, there is a proliferation of networks, especially in the field of agriculture, for example, ACT, IFOAM, DONET, ALIN, SWMNET, SEARNET, MVIWATA, KENDAT, HIMA etc. There are several types of networks and different criteria on which a typology can be based, for instance: (I) the formal/centralized networks tend to have a strong secretariat. Most of the communication is initiated by or passes through the secretariat; (ii) in the more informal/decentralized networks there is direct and systematic communication between the different members of the networks. The center is a support service for any action carried out by its partners; and (iii) other typologies differentiate between scope of geographic coverage (local, national, regional and international), or by distinguishing the subject matter of the networks (e.g., networks on Ecological Pest Management [EPM], on soil fertility, on PTD, on organic agriculture or on a whole range of aspects).

PTD Programs in Ethiopia

In Ethiopia, participatory methodologies in research and farmer outreach programs have also developed over the past few decades (Reij et al. 2001). The early years were fraught with research and extension packages that failed to meet the expected development in agricultural production. A review of the chronology of extension systems in Ethiopia over the last 50 years (UNDP/ECA 1998) indicates many systems have been tried, and they are as follows:

- Provincial Rural Development Program ("Lemat") initiated by Provincial fiats;
- Chilalo Agricultural Development Unit (CADU);
- Wallamo Agricultural Development Unit (WADU);
- Minimum Package Program (MPP);
- Community Development Program
- Peasant Agricultural Development Program (PADEP); and,
- Sasakawa 2000 Project.

The Provincial Rural Development Program (Lemat)

The Provincial Rural Development Program (Lemat) started in the 1950s. Governors of Provinces created development committees known as Lemats. The basic objective was fund-raising for local development projects. Compulsory contributions of money and labor were levied on the local people, and the system had many problems.

Chilalo Agricultural Development Unit (CADU)

The Chilalo Agricultural Development Unit (CADU) approach was contained in a special memorandum of the planning commission "Comprehensive Rural Development Programs in Ethiopia" in 1966. It is important to note that Tanzania was the first African country to adopt the Comprehensive Rural Development Programs. However, these programs (e.g., the million-acre schemes) were not successful and were abandoned in the mid-sixties due to their exorbitant cost. CADU (1967-74) was one of the earliest examples of an integrated rural development project. The main activity was the distribution of inputs such as fertilizer, seeds and dissemination of improved practices (Dejene 1989). The government identified 24 administrative units (*Awrajas*) in high potential areas for comprehensive rural development schemes. SIDA supported the Chilalo Awraja. It was a comprehensive project involving research, extension, credit, marketing, etc. The economic rate of return on investment was about 18 percent over the 10-13 year period.

After the Ethiopian revolution and the agrarian reforms of 1975, the CADU approach was extended to cover the whole of Arssi Region, and the Arssi Regional Development Unit (ARDU) was created. Under ARDU, the model farmer approach was abandoned and CADU's excessive emphasis on improved technology was criticized. ARDU was organized into six departments of which “Extension” was the principal department (Dejene 1989). This department worked closely in the development of cooperative and nonformal education.

Wallamo Agricultural Development Unit (WADU)

This project was established in 1970, in the Wollamo (presently part of the Omo Zone, southern Ethiopia), in the highlands of Soddo and Bolosso. It aimed to achieve economic and social development and also enhance local participation in development. Large cash incentives ranging from 200 to 325 Ethiopian birr (equivalent in those days to US$100-163) per year were used to establish 1,750 settler families and promote a shift from subsistence to cash crop agriculture and increase government tax revenue. To a certain extent research on maize and wheat markets, and on credit facilities were done. The economic rate of return was 13 percent over a 20-year period.

The Minimum Package Program (MPP)

Here, the objective was to provide the minimum services needed by farmers all over the country. These included agricultural extension, credit, cooperative development and feeder roads. MPP was established in 1970. The basic unit was the Minimum Package area, defined as within 75 km of all-weather road, and containing at least 10,000 farmers. It was expected to cover half of the geographic area and the entire agricultural population except those in nomadic areas. The economic rate of return was about 17 percent over a 20-year period.

The Military Socialist Programs (MSP)

The Military Socialist Programs were launched in 1975 by the Military Junta that abolished the Monarchy (the Dergue). These MSPs included an agrarian revolution, cooperatives, “villagization,” resettlement and state farms. The programs were meant to distribute “land to the tiller” and, therefore, organized the rural population into associations, cooperatives, villages and settlement schemes. It also converted ex-commercial farms into state farms. The revolution abolished the absolute monarchical system and created a country of smallholder peasant farmers. The revolution soon overstepped its boundaries forcing people into cooperatives, villages and mass organizations. Production of crops by peasant-farmers was controlled and prices fixed. These programs were not relevant to nomadic communities. Soon, the state farms, which were based on imported technologies and run by bureaucratic methods, became a drain on state resources.

Peasant Agricultural Development Programs (PADEP)

PADEP focused on accelerated agricultural development in high-potential areas of the Ethiopian highlands. The general objectives were to increase food production, support production of cash crops for export, conservation of resources and raise incomes and standards of living. PADEP led to the present programs of agricultural extension based on decentralization of the Ministry of Agriculture. Thus it created zonal departments and *wereda* (district) offices, which were directly involved in the implementation of the various programs (UNDP/ECA 1998).

The Sasakawa Global 2000 Project (SG2000)

SG2000 is a part of the present agricultural extension in Ethiopia. The project is involved in research, extension and implementation of field programs. In 1993, the project had 161 demonstration plots implemented in 2 regions, involving maize and wheat. In 1994, the program grew tenfold and included plots of sorghum and teff. In 1995, the program expanded to 3,211 plots (Quinones et al. 1996). SG2000 relies on services of the national extension system, and during peak work seasons extension workers are paid a lunch allowance. The project provides agricultural inputs on credit to participating farmers. They are requested to pay 25-50 percent of the cost of the inputs as a down payment and to settle the balance at harvest time (Hilhorst and Toulmin 2000). Participating farmers also receive intensive assistance from extension agents on the condition that they consent to the use of their plots for demonstration purposes. Extension agents administer the credit components. However, animal production, soil conservation and forestry seem to be ignored. There is also the problem of monetary incentives creating conflicts among extension workers who are not involved in the project.

When the SG2000 program started, the extension package was introduced to farmers who had better resources and skills, and the ratio of extension workers to farmers was high. Under these conditions, the package was very profitable, even though the improved seed and fertilizer accounted for 50-80 percent of the total costs. Results were less favorable when the package was introduced to farmers working under marginal conditions (low, unpredictable rainfall and less fertile soil). In these areas, local varieties outperformed the improved package in dry areas. The expansion of the package to poorer farmers in less favorable ago-ecological regions thus raises serious challenges for the extension services a well as to the input supply and the banking sector (Hilhorst and Toulmin 2000).

Participatory Demonstration and Training Extension System (PADETES)

Participatory Demonstration and Training Extension System (PADETES), has been the national extension system of Ethiopia, and has so far been implemented satisfactorily. This system, which has been developed after a critical evaluation of the past extension approaches practiced in Ethiopia, accommodates present thinking in extension philosophy that involves research, education and extension as part of the knowledge system. In contrast with the past extension systems, where the focus was limited to either solely technology transfer or human resources development, PADETES puts equal emphasis on both human resource development and the transfer of appropriate and proven technologies. According to the new system, execution of extension is entirely the responsibility of the Regional Agricultural Bureaus, while the Federal Ministry of Agriculture has the mandate to formulate and submit agricultural and related policies and, upon approval, coordinate and diffuse them through interregional development programs and/or projects, and provide technical advice and training services to increase the technical competence of the extension staff of the Regional Agricultural Bureaus (Ejigu 1999).

The National Extension Program

The national extension program was designed to attain food self-sufficiency. The short to medium-term agricultural development strategy, in this regard, would focus on environmentally conscious intensification programs both in traditionally surplus producing as well as drought-prone areas and in nomadic pastoralists areas (Ejigu 1999). The program assisted small-scale farmers to improve their productivity through dissemination of research-generated information and technologies. Though it was limited to only seven regions and 35,000 farmers in the initial year, the program has now expanded to cover over 2.5 million farmers. In addition to increasing the size of farmers involved in the program, a number of developmental packages have been designed and dispatched. Among these are packages on cereal crop production (moist zone and dryland) and packages on livestock production, high economic value crops, post-harvest technologies, agroforestry, soil conservation and beekeeping (Ejigu 1999).

Group Extension

Group extension has been promoted by NGOs, due to the advantage of working with smaller groups. In one such case, Action Aid-Ethiopia helped to form local savings-and-credit groups of 20-30 members. They found that small groups function better and suffer from fewer internal conflicts than village cooperatives (IIRR 1998). This is because the groups are smaller and more manageable, and their members have more in common than do the much larger village-wide cooperatives. The groups can focus on problems they feel are important, rather than those identified by outsiders. However, it was found that regular meetings and refresher workshops were necessary to maintain the groups' skills and enthusiasm. Action Aid provided the groups with advice on coffee cultivation. One or two farmers in each group volunteered to establish nurseries to produce coffee seedlings of different varieties, which are resistant to the berry disease. The farmers were trained in nursery management, coffee production and forestry activities, and were also provided with subsidized seeds. These "resource farmers" established nurseries on their own land and grew seedlings to plant or sell to their neighbors. In 1996, Ato Alemaye Adyeko, one of the resource farmers, sold coffee seedlings worth birr 1,200 (US $175). In 1997, Action Aid began using the same approach to introduce forest-tree seedlings. In the first year, five groups with a total of 50 farmers began raising forest-tree seedlings (IIRR 1998).

Participatory Resource Use Planning (PRUP)

This is an extension system that was facilitated by Farm Africa-Ethiopia. It utilized committees at three levels of participation (Assefa 2000):

- i The Kanta—in Konjo culture forms the center of traditional authority and decision making, and the basis for community concession, consensus, mutual support system and organization of labor and other development inputs. PRUPS starts at this level.

ii The Kebele – is the “lowest” government administrative unit. It has judicial and government functions and it collects taxes but does not decide on or allocate tax revenue. The Kebele council also practices consultation with traditional elders. The Kebele is where project initiatives can be reviewed and authorized, and developed planning validated and costed.

iii The Wereda - Konso is one of the five Weredas reporting directly to the region. Its council can receive, consider, ratify, integrate and provide resources for Kebele development proposals. The Wereda council in consultation with line departments and traditional elders coordinates, normalize, publishes and submits annually developed budget proposals to the region.

One example is the participation of local people in PRUP in the area of Konso. It involved the following steps:

Step 1 Training participants on the basics of planning.

Step 2 Planning Committees formed at Kanta and Kebele levels.

Step 3 Action plan formats filled out.

Step 4 The Kebele Committee prepared plan format of land use, soil type and plant distribution maps on aerial plots. Maps of recent achievements and newly proposed ones are made e.g., land use —fertile versus infertile land, private versus communal land, areas where animal diseases occur, tsetse fly zone and, also in degraded or eroded areas.

Villagization

“Villagization” is a process by which rural households are moved from scattered dwellings into villages, as part of a government attempt to modernize rural life and agricultural production. The first villagization process in Ethiopia was in 1977 — since then, over 12 million people have been affected until 1988. It affected most in Showa and Heraregha, while Tigray, Gamo Goffo and Wello were the least affected (Lirenso 1990). Villagization had many negative impacts on food production, for instance, the National Villagization Coordination Committee (NVCC) in 1986 gave priority to areas growing food crops, while areas with cash crops were to be considered later. It became difficult to obey guidelines e.g., pay special attention to farmlands, pesticide, water resources, roads etc., in site selection, whereas in reality these things were not found together in site selection. Other problems that came on were:

- Significant increases in distance between fields and new homes.
- Difficulty in carrying straw to livestock.
- Peasants being not able to grow vegetables and perennial crops like ensete and chat.
- Not having space to dry cow dung for fuel.
- Houses being too small (30x40m) with some families having ten members.

On the positive side, villagization helped strengthen security, control of bad trade, hold meetings, access to social amenities, shops, water, schools and facilitated re-aforestation.

Training and Visits (T&V) in Ethiopia

The T&V system was introduced in June 1983 in a pilot project in the Tiyo and Hetosa subdistricts of the Arssi Region and the Ada and Lume subdistricts of the Shoa Region (Dejene 1989). It expanded into a third pilot project in the Shashemene and Arssi-Negelle subdistricts in the southern part of Shoa. Approximately 80 front-line extension staff was involved in the project. The T&V system was characterized by a systematic time-bound program of staff training and farm visits. Discipline, a concentration of efforts on agricultural problems, a single line of command, and deliberate linkages with researchers, all assisted in improving the effectiveness of the extension services. The T&V pilot project was based on the assumption that the effective communication of relevant messages is crucial to the adoption of new technology (Dejene 1989; Pickering 1989).

The organizational structure of the T&V system in Ethiopia was similar to that in other countries, except for the chain of command above the district level. The AAEO sent reports on extension in his district directly to the head of the T&V pilot project unit in Addis Ababa, who had overall responsibility for the T&V system. He made most of the decisions required at headquarters and brought issues of major concern to the T&V Pilot Project Committee, which was chaired by the head of the Department of Peasant Organization and Agricultural Development. In this way, the normal regional structure for agriculture was bypassed and the extension chain of command was clarified.

PTD Programs in Kenya

In Kenya, several extension packages have been tried such as the Training and Visits of the 1980s, Farming Systems Research, Catchment Approach Systems (Sherington 1997; Lacy 1996; Norman et al. 1994; Lewcock 1997; Gautam 2000), the PFI (Promoting Farmer Innovation)—(Critchley et al. 1999) and more recently, the National Agricultural and Livestock Extension Project (NALEP 2001) and the Farmer Field Schools Approach (Duveskog 2001). Each of these approaches has, to an extent, propelled smallholder agriculture, albeit with some limitations. The more common programs are given below:

Training and Visits (T&V)

The Training and Visits (T & V) was an extension project funded by the World Bank as part of the National Extension Program (NEP), and was implemented in two phases, viz., NEP-I and NEP-II (Gautam 2000; Pickering 1989). T & V, implemented in 41 districts, was meant to replace the traditional extension system (inherited from the colonial government), which had failed to improve production in smallholder farming as it was fraught with too much bureaucracy. Under T & V, the concept of the model farmer was promoted. Under this concept the progressive farmers were identified and where research experiments and demonstration plots would be set up on their farms was determined. The model farmer would receive regular visits from the frontline extension workers (FEWs), and field days held in his/her farm. It was hoped that visiting farmers would learn from

Table 4. An analysis of the strengths and weaknesses of T&V in Kenya.

Weak points	Strong points
Very broad objectives	Wide coverage
Strong top-down	Coverage of all types of farmers
Target not specific	Strong staff training
Weak farmer participation	Development of professionalism at the district level
Low staff motivation	Strong presence of FEWs
Weak monitoring and evaluation	Procurement of transport equipment and office accommodation
Supply-driven messages	
Donor dependent	
Little flexibility	
Little accountability	

Source: Gautam, 2000

the model farmer and replicate the interventions seen. However, adoption rates were disappointing as the visiting farmers, for one reason or other, could not identify themselves with the model farmer. Gautam (2000) blames this failure on the fact that the FEWs were junior staff, not well trained, and they concentrated on progressive farmers, who represented 10 percent of all smallholder farmers. Table 4 provides an analysis of the strengths and weaknesses of T &V in Kenya.

Local Level Planning (LLP)

Local Level Planning (LLP) was a participatory extension planning tool or process in which various extension agencies working in a given area consult farmers regarding their problems, needs, priorities and aspirations. Subsequently, based on the input received, an extension basket of solutions for that specific agro ecological zone is developed (Holding and Kareko 1997). The package, once implemented, is monitored and evaluated by both the farmers and the officers. The objective being the introduction of farm forestry to small-scale farmers. During implementation, several meetings and farmer training workshops were held. The implementation followed these steps.

- Meeting of Ministry teams and farmers (MoA and MENR).
- Farmer selection, in which three farmers per group (four groups) were selected.
- Each group together with the officers visited the other three groups and interviewed farmers.
- A work-plan was developed including activities such as nursery establishment, beekeeping, poultry-keeping, collecting fuel wood, seed collection and planting of seedlings.
- Training of tree nursery management, beekeeping etc.
- A final review, which involved all participants.

Part of the LLP process was to guide farmers in finding local solutions to their problems. Farmers tend to provide solutions that more often than not, require external assistance. It was the role of the exercise to facilitate identification of such local solutions.

Catchment Approach

The catchment approach to soil conservation was practiced in Kenya for 10 years from 1987-1997. It covered the planning and treatment of farms that were within a certain hydrologically defined watershed, ideally within a single financial year. But this did not necessarily cover the whole watershed area. The program was planned to provide conservation structures even beyond individual farms. The main emphasis was on farm-by-farm planning and implementation, and on on-farm conservation measures. The overemphasis on private as opposed to public land, and upon on-farm measures as opposed to off-farm measures limited wider community-based participation in this program. The extent and quality of involvement of the communities, through their Soil Conservation Committees (SCCs) was relatively low. In spite of the large amount of work done in propagating the ideals and tenets of the catchment-area approach, its success rates were gauged as poor.

An evaluation of the Catchment Approach Program in Embu, Siaya and Nandi districts of Kenya obtained the following results (Admassie 1992):

- i Absence of guidelines to direct the initial process of catchment boundaries led District Planning Teams (DPTs) to deal with it in a haphazard manner;
- ii There was lack of uniformity in the way Land Treatment Plans were prepared in the three districts;
- iii The staffing of the DPTs was also unequal;
- iv Layout work was carried out by only Technical Assistants in two of the districts;
- v The commonly used soil conservation measures were “fanya juu” terraces and napier grass-strips with cut-off-drains and infiltration ditches in Embu, and unplowed strips and napier grass-strips in Nandi. In Siaya, a sort of experiment with all kinds of measures was carried out on the few farms where soil conservation had been attempted;
- vi The task of implementing the recommended measures was the responsibility of the individual farmer in Nandi and Embu. In Siaya, the implementation of measures on the few farms took place through community groups; and
- vii In the successful catchments from Embu and Nandi, where active SCCs were in place, follow-up work (checking out proper implementation and where necessary ensuring that corrective work is done) proceeded smoothly.

The National Agricultural and Livestock Extension Program (NALEP)

The National Agricultural and Livestock Extension Program (NALEP) is the current participatory extension system being implemented by the Ministry of Agriculture and Livestock Development in Kenya (MoA&RD 2000). The project mainly focuses on poverty reduction and empowerment of small-scale farmers by strengthening the capacity of extension staff to meet farmers’ needs. NALEP’s target has been to serve more than 300,000 farmers in 3 years in about 900 focal areas.

Most of the features of NALEP are based on experiences of the National Soil and Water Conservation Program (NSWCP) that came to an end in 2000, after being in operation for 26 years since 1974. NALEP uses the “Shifting Focal Area Approach” which was borrowed from the Catchment Approach Program. As such, the project focused its effort in a given area over a specified period of time. It has bottom-up stakeholder participation in decision-making, planning and implementation of activities as well as structured supervision, reporting, monitoring and evaluation (Baiya 2000).

The NALEP approach organizes farmers into common user groups to access a wider range of services than what was available in the former Catchment Approach. It caters for soil and water conservation, water harvesting, beekeeping, livestock husbandry, agro-processing etc. First, the communities are mobilized through Participatory Rural Appraisals to involve them in project identification and drawing of action plans. A Focal Area Development Committee is democratically elected for each focal area. Those elected are sent for specific training. NALEP collaborates with research institutes such as KARI and ICRAF to facilitate better dissemination of research results (MoA&RD 2000).

Promoting Farmer Innovation (PFI)

Promoting Farmer Innovation (PFI) was a PTD project implemented in Kenya, Uganda and Tanzania, as part of fulfilling Agenda 21 of the United Nations initiative on the Conventions to Combat Desertification (CCD). The basic objectives of PFI were to sustainably improve rural livelihoods and improve ecosystem dynamics through the identification, verification, and diffusion of local innovations related to soil and water conservation, water harvesting and natural resource management (Critchley et al. 1999; M'buru 2000). To achieve its objectives, PFI embarked on a program to: (i) promote farmer-to-farmer exchange visits as a major tool for accelerating the diffusion and adoption of innovative and improved land management, water harvesting and soil and water conservation practices; (ii) build the capacity of supporting organizations to experiment and innovate; and (iii) promote a policy at national level incorporating the need to build on and improve the innovative capacity of land users, and to use innovative farmers in the diffusion process, thus creating a more favorable environment for the rapid adoption of improved resource management techniques.

PFI adopted an approach based on the knowledge and experience that is latent within the community and from recognizing the fact that farmers are better able to learn and adopt new ideas when they see them practiced by others who have similar resources of land, labor and capital. The methodology involved a ten-step PTD as follows (Critchley et al. 1999):

- i Identification of farmer innovators (FIs) and innovations
- ii Verification of innovations and recruitment of FIs
- iii Characterization and analysis of FIs and innovations
- iv Formation of clustered networks of FIs
- v Set up monitoring and evaluation (M & E) systems
- vi FI to FI networks visits

vii Study tours for FIs

viii FIs develop new techniques and experiments

ix Farmers visit FIs

x FIs as outside trainers

PFI started in 1998 and within a year, the methodology of farmer-to-farmer training was proving popular (Thomas and Mati, 1999). Within 2 years, PFI had recruited 40 farmer innovators (FIs) in Kenya, 60 in Tanzania and 25 in Uganda, obtaining an impressive catalogue of different SWC, RWH and NRM innovations. Farmer innovators had been trained and taken on exposure tours, which proved catalytic in encouraging farmers to innovate and adopt new ideas. Although there were advantages in seeking out real innovations, the selection of FIs was too stringent, in not recognizing conventional interventions even where good land management practices that combat desertification were in place, whether they are truly innovative or not had been applied. Closer collaboration with research institutions and universities to enhance research activities in order to verify and improve the innovations also required attention. Otherwise, the PFI methodology rekindled interest in farmer innovations in the region.

Farmer Field Schools

The Farmer Field School (FFS) is described as a "school without walls." It is a participatory method for technology development and dissemination, which gives the farmer an opportunity to make informed decisions about farming practices through discovery-based learning (Okoth et al. 2002; Duveskog 2001). The school involves 25-30 farmers in a given locality and facilitates in finding solutions to their problems. The main objective of FFS is to bring farmers together in a learning environment to undergo a participatory and practical season-long training pertaining to a particular topic. The focus is on field observations, hands-on activities and season-long research. The emphasis is on empowering farmers to implement their own decisions in their own fields. Within this form of training, problems are seen as challenges and not as constraints, and participants learn also to identify and tackle any problem they might encounter in the field.

In 1999, the FAO Global Facility launched an East African sub-regional pilot project for Farmer Field Schools on Integrated Production and Pest Management (IPPM) in three districts in Kenya, three districts in Uganda and two distrcts in Tanzania (Okoth et al. 2002). In Kenya, 1,000 FFS groups of 20 to 25 persons each were started. The FFSs worked on locally available sources of nutrients, improved fallow, the use of Mucuna and green manure and compost making. They also worked on HIV/AIDS awareness and coping strategies. By 2002, about 250 extension workers and 34,000 farmers had been trained through FFS. The main constraints with FFS are: (i) changes in attitude takes time; (ii) many facilitators still have limited participatory skills; (iii) documentation needs time; (iv) practical information for farmers is lacking; and (v) internal information flow hitches. Although the cost of training professionals in FFS is high, the overall approach is cheap and cost-effective as a result of farmer facilitators being basically volunteers.

Farming Systems Research (FSR)

Farming Systems Research (FSR) also known as On-farm Adaptive Research (Moris 1989; Norman and Douglas 1994; Norman et al. 1994) was aimed at identifying options for improving the well-being of rural households in specific local environments. It had four main characteristics (Upton 1987): (i) working on-farm with households/farmers; (ii) FSR was locale-specific, thus each subprogram related to a limited number of similar farms in a given locale; (iii) FSR was holistic and, therefore, concerned with the whole farming systems, and its interdependence rather than with individual elements (such as commodity programs); and (iv) FSR involved multidisciplinary teams of researchers. In Kenya, FSR was implemented through KARI.

In essence, FSR used multidisciplinary investigative teams. It relied on rapid reconnaissance methods for identification of interventions and stratified packages to suit different resource and managerial levels (Moris 1989). The problem was that FSR took on too many goals and, therefore, became very complex and thereby limiting its implementation. FSR worked on scientist-to-farmer transfer of technology modes and gave low priority to local knowledge. It demanded continual access to farmers' fields as on-farm adaptive trials had to be carefully supervised. This became a drain on the resources beyond what research stations could accommodate. To cope, extension agents were included in the on-farm trials. Direct two-way linkages between researchers and district extension staff seemed to violate protocol at some levels. Moreover, the organization of FSR into units located at specific research stations could not go together with the extension line of command. Another issue was how to coordinate FSR alongside the T & V extension, which was operational then (1980s). This was resolved through joint meetings and by 1985, the Ministry of Agriculture had integrated FSR into its extension systems. Despite all these problems, FSR introduced the practice of research with farmers, and its success lay in looking at the farm as a holistic unit, whose problems and solutions are integrated.

Agricultural Technology and Information Response Initiative (ATIRI)

Agricultural Technology and Information Response Initiative (ATIRI) is the current participatory research program being implemented by KARI. The objectives of ATIRI are to improve farmers' ability to make demands on agricultural service providers and to enhance the effectiveness of intermediary organizations and farmers' groups in meeting the knowledge needs of their clients and members (KARI 2001a). Unlike in previous research programs, where proposals were developed by scientists, under the ATIRI approach, proposals are formulated by farmers' groups through their CBOs (Community-Based Organizations). However, the CBOs may seek assistance from approved intermediary organizations such as universities and NGOs.

Under ATIRI all activities focus on the identification, adaptation and promotion of new technologies and methods (new to the participating farmers) as well as preservation and dissemination of ITK (Indigenous Technology Knowledge). The major activities that are supported by ATIRI include:

- Short-term nonacademic (hands-on) training to enhance the skills of staff working for intermediary institutions and farmers' leaders.

- Activities that identify potentially replicable elements of ITK, and lessons learnt in technology testing.

- “Pump-priming” supply of inputs, including basic seeds for multiplication and sale by farmers’ groups, equipment or minor civil works for testing, which can be advanced either as matching grants dependent on cost sharing by CBO or as seed-funding for group managed savings and loan institutions.

- Piloting of technologies and institutional arrangements when a substantial scale of operation is required to confirm their feasibility for wider replication.

- Preparation and dissemination of information materials and other networking activities.

- Monitoring, evaluating and reporting on experiences including preparation of publications, videos etc.

Another example of KARI’s research project is the SFRRP (Soil Fertility Recapitalization and Replenishment Project) implemented by ICRAF, KARI, KEFRI and NGOs in Maseno, near Kisumu (KARI 2001b). Farmers are encouraged to form village committees mainly for the purpose of testing technologies developed by KARI and other research organizations. The committees elect representatives to serve on higher-level committees at sub-location and location levels that act as channels for two-way communication between researchers, extension staff and farmers.

PTD Programs in Tanzania

In Tanzania, there have been trends towards participatory research and extension, with some good results such as the PFI methodology (Critchley et al. 1999) and the Indigenous Soil and Water Conservation Project (Reij et al. 2001). Like Ethiopia, Tanzania has undergone major policy changes from the socialist villagization programs of the 1970s to liberalized economy in the late 1980s (Lazaro et al. 2000). Thus there have been marked improvements in both agricultural and economic growth, positively affecting research and extension in the country (World Bank 2000). Some of the extension programs are given below.

The SCAPA Approach

The Soil Conservation and Agroforestry Project-Arusha (SCAPA), was an extension project in the Arusha Region of Tanzania. It was meant to facilitate agriculture, forestry and animal husbandry experts and extension workers to work together and develop integrated extension packages that would enhance conservation and production (Assmo and Erickson 1994). SCAPA utilized the “Catchment Approach” methodology and it reached 4,500 farm households. The project involved the following steps: (i) preparation and organization; (ii) identification of needs, beginning with small groups of 5-20 farmers who are committed; (iii) contact local leaders; (iv) survey the catchment; (v) initial meetings with farmers and stakeholders; (vi) selection of Soil Conservation Committees; (vii) training of local leaders and SCC members; (viii) planning of the activities; (ix) training and study tours for farmers; (x) implementation of field activities (i.e., soil conservation structures, tree planting etc.,); and (xi) supervision and follow up.

The Land Management Program (LAMP)

The Land Management Program (LAMP) was a SIDA-supported district-based land husbandry program in northern Tanzania with “increased productivity in the use of natural resources in a sustainable way” as its development objective. Having started in 1991, it n covered the semi-arid districts of Babati, Kiteto and Simanjiro in the Arusha Region, and two divisions of Singida Rural District (Elwell et al. 2000). These districts are characterized by a bimodal rainfall pattern and may be grouped as semi-arid. The average annual rainfall for Babati, Kiteto and Simanjiro districts are 790 mm, 609 mm and 487 mm, respectively. Rainfall distribution is highly irregular. LAMP worked through mechanization of agricultural activities and conservation tillage. However, mechanization in Babati was above average and has been for over 30 years. Except for Singida, where hand-hoeing and ox-cultivation dominate, about 60 percent of the land was plowed by tractors, 30 percent by oxen and 10 percent by hand (Elwell et al. 2000). Studies in Babati showed that crust pans developed on most farms. Deep tillage with tine implements was tried with very positive results, compared to conventional plowing (Hatibu et al. 2000).

LAMP operated as a funding agency rather than a conventional development project. The Babati District Council was the implementing agency with technical support from Orgut, a consultancy firm. The LAMP support was guided by the overall objective of increased productivity in the use of natural resources in a sustainable way. These included dryland farming techniques which incorporates conservation tillage, soil fertility management (crop residues, farmyard manure and rock phosphate), post harvest practices, agroforestry and improved livestock management (Hatibu et al. 2000). A major limitation was inadequate rainfall (a common feature) in the Singida Region, which resulted in farmers being, at times, unable to cope with the effects of drought.

Hifadhi Ardhi Dodoma (HADO)

The Hifadhi Ardhi Dodoma (HADO) project was launched in 1973 by the Government of Tanzania with financial assistance from SIDA. HADO was implemented in three geographically separate areas in the Dodoma Region —the Kondoa Eroded Area in Kondoa District, Mpwapwa District, and from 1986, in Mvumi division of Dodoma rural district (Hatibu et al. 2000). The project used mechanical methods such as graders and other machinery to construct soil bunds for gully control. However, the most radical aspect of the project was the forced movement of all livestock, especially from the Kondoa Eroded Area in 1979, to allow degraded lands to recover better. The project also supported reforestation and soil conservation programs. Thus, several hundred hectares of woodlots were established centrally by the project. During the final years, the project concentrated more on supplying seedlings from the project-operated nurseries. The project also facilitated extension, education and training.

An evaluation of HADO undertaken in 1995 by the Swedish International Development Agency (Sida) and the Ministry of Tourism and Natural Resources, provided examples of some interesting weaknesses (Hatibu et al. 2000):

i In the Dodoma Region, crop yields are reduced more by shortage of soil-moisture rather than by loss of soil. Hence, HADO should have had more emphasis on rainwater management within the croplands rather than erosion control.

ii The objective and strategies of HADO were oriented towards land rather than the people in the project area.

iii The work on croplands was focused on water runoff disposal and addressed important rainwater productivity aspects marginally.

iv Key extension messages were rather traditional, for example, improved seed and row planting. Soil-water management did not figure prominently among the messages.

v There was very little follow-up to determine the survival rate of thousands of seedlings distributed free to villages, schools, other institutions and individuals.

vi The emphasis on the "fanya chini" contour ridging was ineffective in controlling erosion.

vii Many of the gully control structures failed due to poor construction or maintenance, and gully development continued in many places.

viii The need to change the strategy from a narrow focus on erosion control to a broader holistic land husbandry approach.

The HADO experience provides good lessons for planning land use and water resources programs. One good lesson is that HADO suffered from lack of clear and integrated policy direction. As a result, what should have been a multisectoral and multidisciplinary project was dominated by only one sector. There is no evidence of a thorough planning stage that took into consideration all the alternatives and screened them vigorously. In planning land resources programs the emphasis should be on enabling the people to manage soil, water and vegetation resources in ways that enhance conservation while increasing productivity (Hatibu et al. 2000). Even with such limitations, the HADO project offers many lessons to guide planning of similar programs.

Indigenous Soil and Water Conservation Program (ISWCP)

The ISWCP (Indigenous Soil and Water Conservation Program) — (Kibwana 2000) developed a research methodology to identify and work with innovative farmers in Tanzania. It lists eight steps: (i) joint PTD workshop for researchers and "extensionists"; (ii) identifying and analyzing farmer innovators and their innovations; (iii) training for farmer innovators; (iv) farmers learning from farmers viz., cross visits among farmer innovators; (v) follow-up on cross visits; (vi) developing themes for joint experimentation; (vii) learning together viz., joint experimentation; and (viii) reflection and planning. ISWCP worked very well to integrate experimentation by farmers, extension workers and researchers, which resulted in having high adoption rates among nonparticipating farmers.

Under the ISWCP approach, researchers and extension workers were trained in the use of tools for participatory learning, while farmers were trained on methodologies of experimentation (Mruma and Temu 1999; Mwale and Mruma 1999). ISWCP placed much emphasis on farmer knowledge and sought to empower and motivate them by sharing and learning in partnership with researchers and extension workers. Training was a major component of ISWCP, which was followed by rapid surveys (in Njombe, Mbozi and Isangati districts) to identify innovative farmers. The concepts and methods of participatory technology development were explained and employed at the workshops held with innovators. In the field, farmers set up experimental plots, which they monitored in combination with researchers and "extensionists." The results of experiments were shared during farmer-to-farmer visits and in village workshops with the aid of extension workers (Kibwana 2000; Thomas and Mati 2000). ISWCP was one of the programs with a very strong PTD component, and in which farmer experimentation received serious commitment by farmers and high adoption rates among nonparticipating farmers.

Conclusion

This chapter has enumerated some of the approaches used in learning and technology transfer to smallholder farmers in East Africa, especially on programs which had strong water and soil nutrient management components. That these approaches are not exhaustive is in no doubt. What emerges is that no single approach can be said to have been truly successful, and subsequently, none was a total failure either. However, even with all these different approaches such as PTD, participatory approaches, farmer research, the fact remains that smallholder farmers in East Africa are still disadvantaged in terms of competitiveness with other farmers in the world. Not to underrate the gains made, there have been substantial improvements in different localities where farmers have benefited from interaction with researchers, extension workers and knowledge in general, and these have been well documented. Indeed this forms the focus of NEPAD's CAADP, where it is hoped to learn from successes, and out-scale from them. But there is a need to learn from failures too. The shortcomings highlighted here help provide some painful lessons, which can be used by future generations to achieve better results.

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