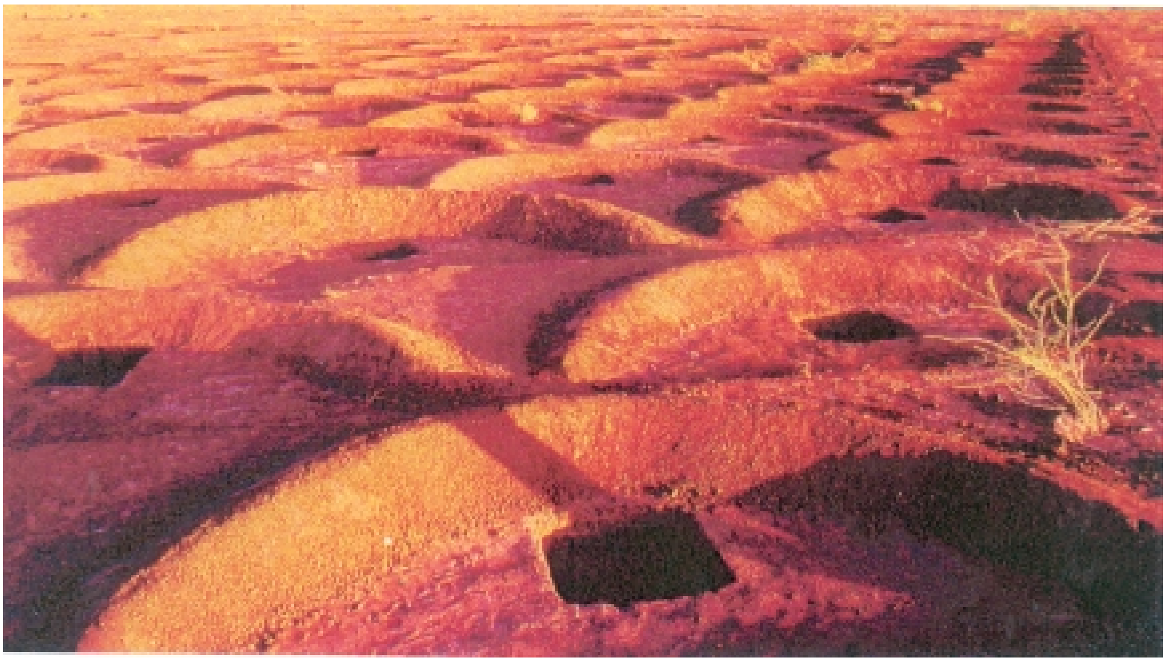
Costs and Benefits of Adopting Runoff Irrigation Systems

A case study from Kakuma, northern Kenya



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This work is dedicated to the people of Kakuma.

Abstract

The Turkana, a nomadic tribe in the arid northwest of Kenya, are becoming increasingly settled. Their contact with modern civilization has gone along with poverty, famines and desertification around settlements, where people and livestock were concentrating beyond the carrying capacity of a fragile ecosystem. The situation resembles those found throughout many drylands in development countries. One of the approaches to deal with this development has been to introduce runoff irrigation systems. These systems retain surface runoff generated by rainstorms, using the water to grow trees and crops. So far, adoption of these systems by the Turkana has been poor despite their proven ecological effectiveness. This paper presents an economic case study of a new concept to plant fruit trees in such systems. In the context of Turkana settling near a refugee camp in Kakuma, northern Kenya, the following question was addressed:

Under the local conditions, is it profitable for the Turkana to plant fruit trees in runoff irrigation systems?

Using the framework of financial cost-benefit analysis, the study outlined a number of hypothetical scenarios based on local pilot projects. Three fruit tree species (mango, guava, papaya) were investigated in two different irrigation systems (micro- and macro-catchments). In the micro-catchment system, a number of semi-circular earth bunds harvest surface runoff from a gentle slope. In the macro-catchment system, water from an intermittent stream is guided into leveled basins. Both systems were compared against the traditional sorghum farming of Turkana agropastoralists.

Key informant surveys and market studies were used to ascertain local input parameters, complemented by basic ecological modeling and literature data on fruit yields to detail the scenarios. Net present value, benefit-cost ratio and internal rate of return were used as decision criteria for the cost-benefit calculations. A sensitivity analysis served to investigate relative importance of the input parameters and to allow an error estimate.

In conclusion, cost-benefit analysis proved a useful tool in simulating decision-making by the local population. Runoff irrigation was shown to be profitable in Kakuma, building on and improving traditional agricultural techniques. A papaya plantation has a clear advantage over a mango or guava farm, resulting from the lower total water requirements of papaya and the

high discount rate applied in this study. The macro-catchment system performs better than the micro-catchment system.

Despite profitability of the irrigation approach, construction and maintenance of the irrigation system require substantial initial investments. This is particularly true for the macro-catchment scenario. Adoption is constrained by the availability of capital, traditional division of labor in the Turkana society and the risk of loosing invested capital to a drought. Although the adoption of runoff irrigation reduces the risk of crop failure, economic risks appear to be increasing.

Chapter 1

Introduction

1.1 Background

Worldwide, nomadic peoples are becoming more sedentary. For centuries, this has been an evolutionary process of cultures adapting to agriculture and urban life (RENFREW 1990). Today, contact between traditional societies and the accelerating development of our modern civilization has become increasingly disruptive.

The Turkana district[1] in northern Kenya provides an example of such an encounter. For 500 years, the Turkana have lived a nomadic life based on roaming livestock. This allowed them to pursue a strategy of opportunistic resource exploitation in equilibrium with an arid ecosystem (MCCABE 1991). Increasingly in the twentieth century, development of infrastructure went along with settlement of destitute pastoralists (HOGG 1987). A Norconsult study (NORCONSULT 1990) explains:

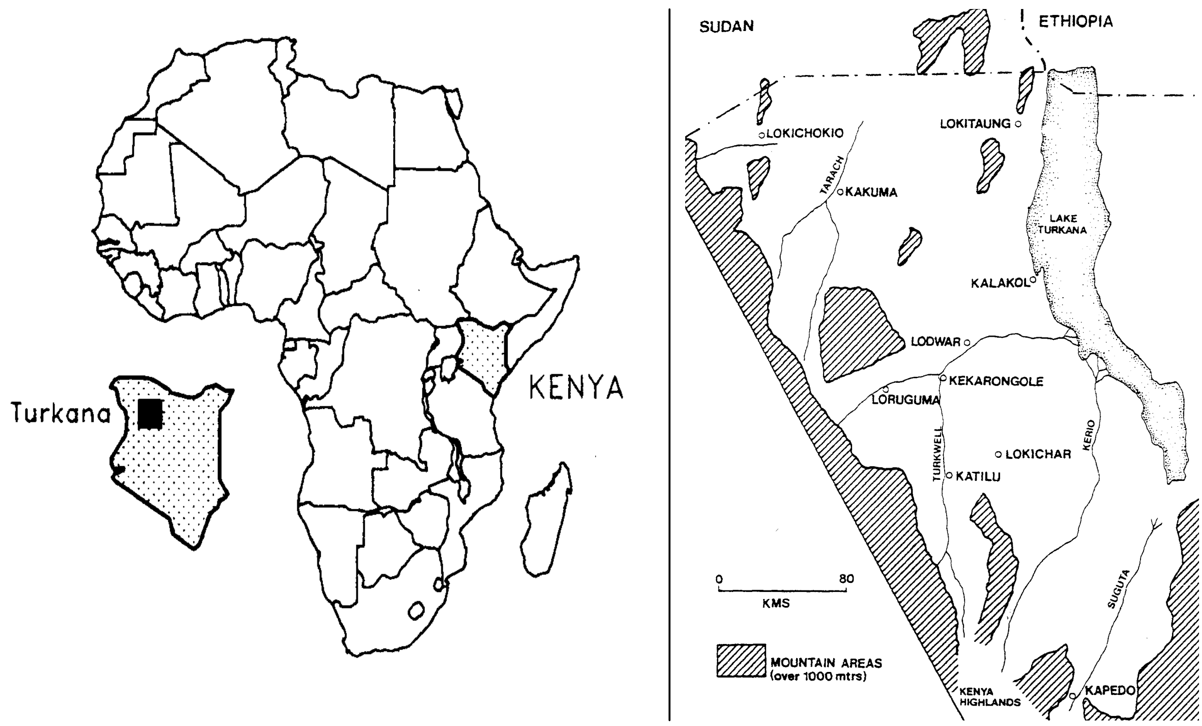
> “A heavy price was paid for environmental sustainability in Turkana in the past. Ecological stress was relieved by the starvation of livestock that failed to secure a sufficient intake of fodder. After a drought, firstly the range and then the herds recovered. Ecological balance was restored. In the meantime, many people who depended on livestock products had died. Such harsh re-adjustment is unacceptable to the people of Turkana and the government of Kenya in the late twentieth century.”

In the settlements, many Turkana turned to cutting trees for firewood, charcoal and timber, as these were among the few traditionally produced items of value in the modern sector (ODEGI-AWUONDO 1990). Concentration of livestock and people beyond the carrying capacity of the fragile ecosystem led to desertification around town areas and turned episodic droughts into devastating famines. With the Turkana becoming increasingly dependent on food aid, the

[1] The expression “Turkana” refers both to the geographical location and to the tribe.

Kenyan government, but also international developing agencies were pushed to act. One of the measures taken was to set up irrigation schemes, aiming at both income opportunities for the Turkana and reforestation of degraded land. Large-scale "food for work" projects often employed several thousand families (REIJ et al. 1998). The growth of settlements continued, but most of the irrigation systems were abandoned after the projects funds were withdrawn.

Kakuma in northern Turkana is such a settlement. Since 1990, the area hosts a refugee camp, accommodating around 65,000 people fleeing civil wars in Sudan, Somalia and other East African countries. Operating under the auspices of the United Nations High Commissioner for Refugees (UNHCR), a number of developing agencies provide relief aid to the refugees. At the same time, Kakuma has become the home of some 30,000 Turkana. The major reason for these Turkana to settle down was the loss of their traditional livelihood after a drought had killed their livestock.



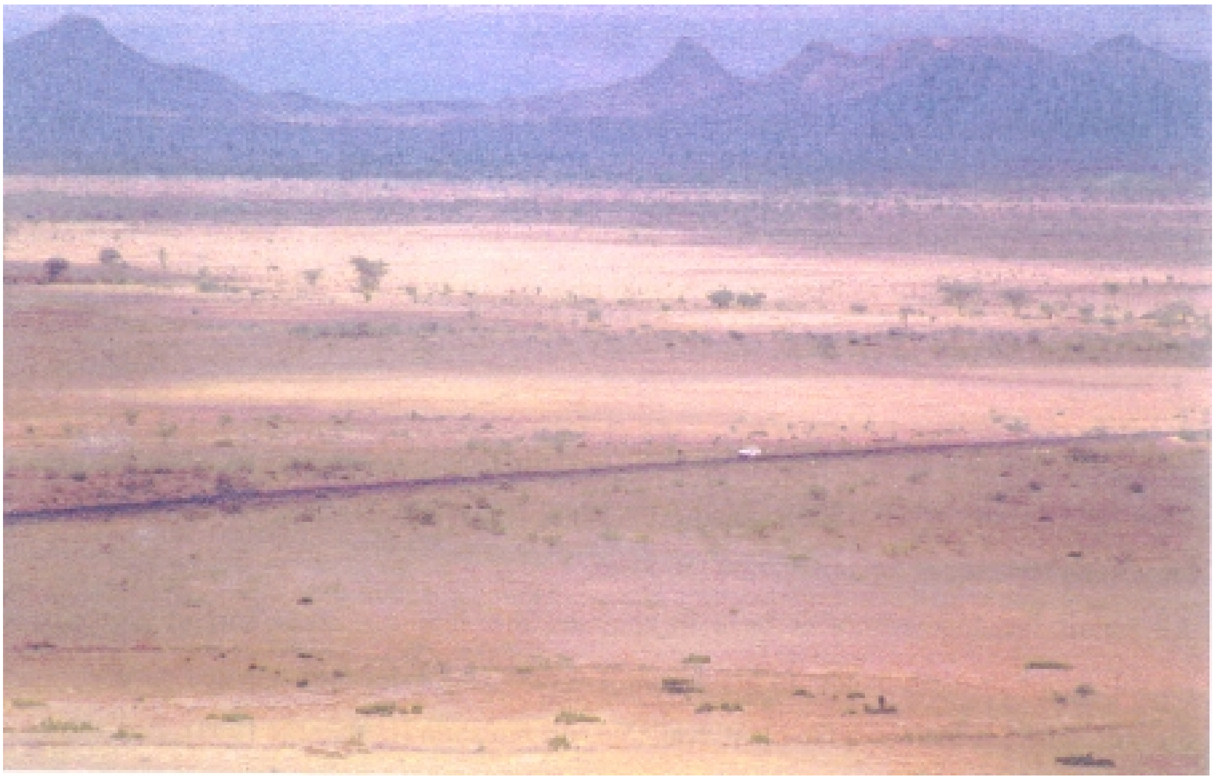
Map 1 Location of Turkana in Kenya (LEACH & MEARNS 1988) and the Turkana district (HOGG 1987).

1.2 Environmental situation of Turkana

The Turkana district encompasses an area of 62,500 km^2 (map 1), most of which is arid. Rainfall varies between 600mm in the western mountains of the district and less than 200mm in the central areas, with rains falling mainly during one of two rainy seasons: the “long rains” from March to June and the “short rains” from September to November. Rainfall patterns both within and between years are highly erratic, with single-year or even multi-year droughts occurring. The climate is very hot with monthly mean temperatures around 30°C. Maximum daytime temperatures are around 40°C (LITTLE & LESLIE 1999).

Kakuma has an average annual precipitation of 318mm (LEHMANN 1998). The town is located on the floodplains of the “Lugga” (seasonal river) Tarach, which originates in the mountains of neighboring Uganda. Groundwater beneath the dry riverbed serves the local population as a source of drinking water.

The vegetation mostly consists of thorn bushes. *Acacia reficiens* Wawra. and the introduced *Prosopis chilensis* (Mol.) Stunz. dominate the plains, while *Acacia elatior* Brenan and *Acacia tortilis* (Forsk.) Hayne can be found along the seasonal rivers. Natural regeneration is sparse and the area around the camp is significantly deforested.



The Turkana district in the vicinity of Kakuma refugee camp

1.3 Turkana settlement in Kakuma

Most Turkana live in their "Manyattas" (traditional huts) in close proximity to the refugee camp, some have settled in the town itself. The majority of the Turkana still possess some livestock, mostly sheep and goats, but also donkeys and camels. Besides livestock keeping, a number of Turkana practice opportunistic rainfed agriculture, where sorghum is sown in the rainy season and harvested two to three months later.

The social unit of the Turkana is the extended family. The traditional division of labor consists of men taking responsibility for livestock and women cultivating the fields and performing other income generating activities. Children traditionally look after the herds of small livestock. Although traditional activities still play an important role for the settled Turkanas, many of them depend on income opportunities provided by the existence of the refugee camp. As the refugees are not permitted the use of natural resources outside their settlement area, many Turkana make a living from delivering firewood, charcoal, and fencing material into the camp. Some Turkana work for the international aid agencies present in Kakuma, a larger number in refugee households. Others are traders, sell home-cooked food or earn money by transporting commodities within the camp.

1.4 Water harvesting and runoff irrigation

Rainfall in arid areas such as Turkana occurs mainly in the form of rainstorms. Single rainfall events of 40mm and more generate large amounts of surface runoff. Extensive flash floods pass over the land surface before finally percolating into the ground. One of several possible approaches to irrigation culture in arid environments is to make use of this runoff water to grow trees or crops.

(Rain)water harvesting is the process of concentrating rainfall as runoff from a larger catchment area in a smaller target area (OWEIS et al. 1999), irrespective of what this water is used for (BRUINS et al. 1986). Runoff irrigation (or runoff farming) is the use of water harvesting techniques for agricultural purposes.

All runoff farming techniques have in common that they use some sort of embankment (mostly stone or earth bunds) to block runoff water. The water thus retained percolates into the soil, where it increases the plant available soil moisture (LEHMANN 1997). Depending on the amount of water harvested, various types of crops and trees can be grown on the irrigated fields.

In practice, numerous different types of runoff irrigation systems have been put to use; in general, two major kinds of systems can be distinguished. Runoff farming in macro-catchment systems is based on the diversion of natural drainage courses on the hillsides of a watershed, leading the water to a chosen site via a system of channels. Micro-catchments refer to a number of small plots each enclosed by an earth wall. Built on gently sloped surfaces, micro-catchments harvest runoff water directly from the adjacent surface area.

In drylands, runoff farming has a number of advantages over conventional irrigation techniques. First, it is significantly cheaper to use rainwater runoff that to tap water from other sources. Second, runoff irrigation structures do not (necessarily) require large structures or expert knowledge, but can be implemented using local resources. Third, runoff farming reduces erosion and serves as an effective method of soil and water conservation (THOMAS 1997). Finally, water harvesting often coincides with nutrient harvesting, as runoff water carries silt and nutrients which are deposited on the cultivated fields.

1.5 Runoff irrigation in Kakuma

Runoff farming techniques have been used in Kakuma since the 1980s, when the Turkana Rehabilitation Project (TRP) and the Norwegian Aid Agency (NORAD) devised several irrigation projects in the area (HUGHES 1997). Currently, the German Technical Cooperation (GTZ) is establishing "Greenbelts" of micro-catchments around the refugee camp, planting native species for reforestation purposes as well as food crops in these schemes. In addition to this, an international research project (LEHMANN 1998) built a macro-catchment type water harvesting system in 1994, investigating an agroforestry system under runoff irrigation. In later stages of the project, LEHMANN (1997) was able to prove the ecological viability of fruit trees in his runoff system, concluding that

> "...preliminary experiments with [...] mango, papaya, guava and citrus in the runoff irrigation system in Kakuma have been very promising. Fruit tree production [...] could revolutionize crop production in northern Kenya."

In Kakuma, fruit is consumed mainly by the refugees, seeking to complement the food rations they receive as part of their relief aid. Currently, traders deliver fruit from adjacent districts to sell them locally. Consequently, producing fruit in Kakuma provides an opportunity for income generation. Further potential benefits of a runoff-based fruit tree plantation include the mitigation of gully erosion around the camp (OWEN 1998), an improvement of the nutritional status of the local population, and a reduced pressure on natural resources.

1.6 Scope of this study

In general, a project can have a number of environmental, social and economic benefits irrespective of who implements it and at which costs. The need for dryland agriculture in particular has often been justified on the basis of food security for a growing world population (LIVINGSTONE 1991). However, development agents agree that projects should be self-sustainable after being handed over to the beneficiaries (GTZ undated), and this depends on people's incentives to adopt the projects introduced to them.

This work deals with the adoption of runoff irrigation techniques. Using the methodology of cost-benefit analysis, it was investigated whether a new land-use technique has the economic potential to be adopted by the local population. The central question of this work is phrased as follows:

> Under the local conditions of Kakuma, is it profitable for the Turkana to plant fruit trees in runoff irrigation systems?

The study develops two hypothetical scenarios (using a micro-catchment and a macro-catchment approach) for a commercial plantation under runoff irrigation, based on local pilot projects. Three species of fruit trees, mango (*Mangifera indica* L.), guava (*Psidium guajava* L.) and papaya (*Carica papaya* L.), are investigated in each of the two irrigation systems. Economic decision criteria measure profitability. Additionally, the results are compared against the traditional rainfed agriculture of the Turkana.

Certainly the decision to adopt a new land use technique involves many considerations, economic profitability being only one of them. Fig. 1.1 places the above question in the context of important determinants for the adoption of runoff irrigation in Kakuma.

On the environmental side, the soil and water conservation qualities of water harvesting constitute an important benefit. Nevertheless, REIJ et al. (1998) caution:

> “It has often been assumed that the benefits [of water harvesting] need a long time to materialize, and the allocation of funds was justified on the basis of preservation of the land for future generations. However, [...] peasant farmers in Sub-Saharan Africa, many of whom live in conditions of poverty, can’t afford to wait for long-term benefits, and they will be more likely to adopt conservation techniques which offer rapid benefits.”

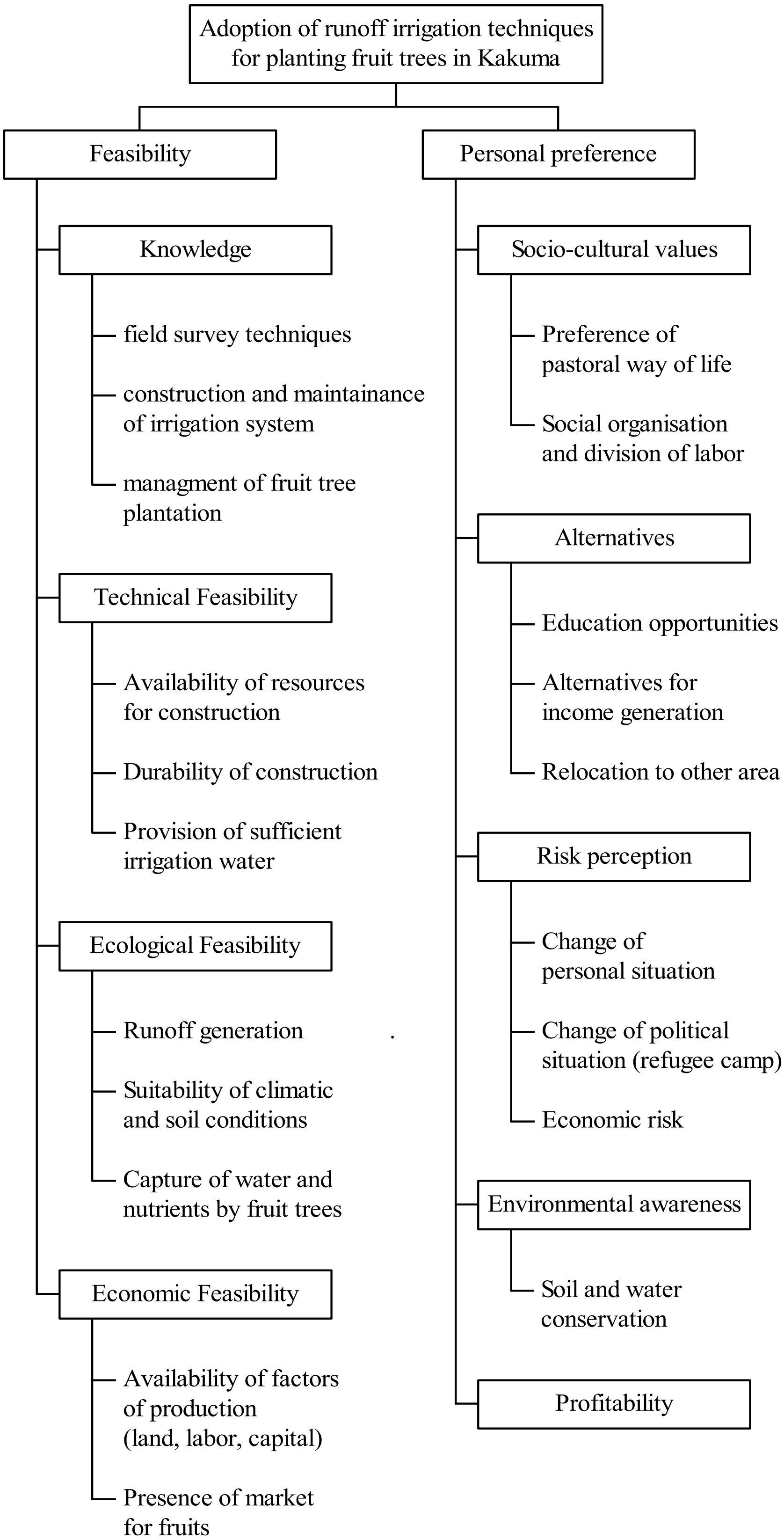


Fig. 1.1 Factors influencing the decision-making of the local population in Kakuma with regard to adoption of runoff irrigation techniques

A second aspect that deserves to be mentioned here concerns the cultural prejudices of pastoralists against agriculture. Development attempts to introduce farming techniques to pastoralists have seen numerous failures in the past (HOGG 1988) and have been widely criticized (for example BARROW 1991 and SCOONES 1996). Turkana who see an eventual return to the pastoral sector as the sole objective of their settlement (BEST 1981) will at best adopt agricultural techniques temporarily. However, cultural evolution also implies an adaptation to economic necessities. BARROW (1996) notes that

> "...this is of particular relevance when considering the arid and semi-arid pastoral ecosystems, where the people have complicated land management strategies that help mitigate against the vagaries of climate and the harshness of the land. As a result, such people are cautious and conservative and such conservatism may, in point of fact, be related to rational economic behavior once the full scope of local decision making criteria are understood."

The fact that cultural behavior can not be completely separated from economic decision-making emphasizes the importance of economic analysis.

The Turkana in Kakuma are livestock keepers that have diversified into a number of other sectors, partly because of poverty and partly because of change imminent in their society. The purpose of this study is to gain an insight into the economics of runoff irrigation, not to contribute to the current discussion about pastoral development.

Chapter 2 provides the theoretical background of cost-benefit analysis and explains the decision criteria used to measure profitability in this study. The chapter also details the methods of data collection used.

Chapter 3 outlines the baseline data for subsequent analysis and outlines the parameters entering cost-benefit calculations. The information is divided into general data reflecting the local situation and data that is particular to the scenarios investigated. Chapter 3 also specifies these scenarios.

Chapter 4 presents and discusses the results of the scenarios outlined, applying the methodology described in Chapter 2 to the baseline data presented in Chapter 3. In addition to the decision criteria, a sensitivity analysis examines relative importance and uncertainty of the parameters entering the cost-benefit calculations.

Chapter 5 draws general conclusions and provides an outlook to the economic prospects of runoff irrigation in Kakuma and to similar situations of tropical drylands in developing countries.

Chapter 2

Theoretical Background and Methods

2.1 Introduction

This Chapter gives an overview of the methodology used in this study. Chapter 2.2 summarizes the theoretical background of cost-benefit analysis and outlines the decision criteria applied in the subsequent analysis. Chapter 2.3 describes the methods of data collection used to obtain the baseline information presented in chapter 3.

2.2 Theoretical background of cost-benefit analysis

Cost-benefit analysis provides the technical tool to judge whether involvement in a certain project[2] is economically beneficial. To achieve this, project-associated costs and benefits are benchmarked against the conditions expected in the absence of the project.

2.2.1 Social and financial cost-benefit analysis

In general, two types of cost-benefit analyses can be distinguished: social and financial cost-benefit analysis (LITTLE & MIRRLESS 1980). Social cost-benefit analysis is a branch of welfare economics, adopting the point of view of the society. Social cost-benefit analysis asks which decision is best when project costs and benefits to the society as a whole are taken into account. It is not dealt with here, since we try to answer the question of adoption by the local

[2] The term "project" is used here to describe any delimited undertaking for which the costs and benefits are considered. For the theory of cost-benefit analysis, the nature and scale of the project itself is not important. In this study, the "project" is the adoption of a land use techniques for planting fruit trees.

population. From an economic point of view, this will depend on individual as opposed to communal costs and benefits.

Financial cost-benefit analysis[3] looks at profitability from the point of view of an individual who implements a project. Financial cost-benefit analysis takes into account costs and benefits as they accrue to that person.

Social and financial cost-benefit analysis make use of the same concept and calculation procedures. Their main difference is that of the point of view adopted. What is beneficial for an individual does not necessarily have to be beneficial for the society as a whole. For example, zero-sum money transfers are clearly beneficial to individuals but usually do not generate benefits to the society.[4]

2.2.2 Calculation principles and decision criteria

The basic principle of a cost-benefit analysis is to list all input into and output from a project, express them in monetary terms, and subtract the costs from the benefits to obtain a net value for the project. If the net value is positive, the project is accepted – if it is negative, then the project is rejected (GRIFFIN 1998).

Complicating the issue is that economic flows may take place at different points in time, and have to be valued accordingly. Future benefits and costs have to be discounted to capture the preference that individuals express for present over future consumption.

Essentially, this reflects a bias towards the present at the expense of the future. Having a certain amount of money today is worth more than obtaining the same amount at a later time. Applied to the example of a fruit tree plantation, the costs of planting arise at the beginning of the project, while the benefits (realized by selling harvested fruit) arise at a subsequent project

[3] The term "financial cost-benefit analysis" (also called "discounted cash flow (DCF) analysis" in the business world), is somewhat misleading, as not strictly financial benefits are considered, but all benefits that can be directly assigned to the persons who implement a project.

[4] An important example of diverging private and social benefits is the "tragedy of the commons"- paradigm (HARDIN, 1968), providing an economic explanation of environmental degradation. In its original version, it deals with the problem of overgrazing in a situation where herders maximize individual benefits by excessive use of grazing lands, yet cause degradation (and thus damage to the society) by overuse of ecosystemary resources.

In fact, in Kakuma area a similar problem arises, with sedentary Turkana cutting trees for firewood and charcoal to sell it to the refugees. Although this allows the Turkana to generate income for their families, it also creates an island of desertification around the settlement.

stage. Consequently, the benefits have to be greater to warrant this time diverge and render the project as a whole profitable.

In cost-benefit calculations, time preference is expressed by a "discount rate", acting in the same way as an interest rate for obtaining a loan from a bank. Interest is the premium for the bank to lend money at present time and receive it back later. For the debtor, having money at his disposal warrants the higher amount he has to pay back.

It is possible to calculate the value for every single cost or benefit in present-day terms, using the general interest formula

$$Present\ Value = \frac{Nominal\ Value_t}{(1+r)^t}$$

where r is the discount rate applied and t is the time (in years) when the cost (or benefit) is accrued. For example at an interest rate of 10%, a sum of 110 KSh[5] received one year from now has a present value of 100 KSh.

There are several methods to calculate a final result, and decide whether to accept or reject a certain project. The indicators resulting from these calculations are called "decision criteria". All methods are equally valid, a project accepted by one criterion will also be accepted on the basis of the other criteria.

The first method is to compute the "net present value" (NPV) by discounting all costs and benefits to the present day and balancing them. For example, if costs of 50 KSh today go in line with anticipated benefits of 110 KSh one year from now, a discount rate of 10% will yield 100 KSh worth of benefits today, resulting in a NPV of 50 KSh. In general, the NPV is calculated using

$$NPV = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t}$$

where B_t and C_t are the benefits and costs in year t and r again is the discount rate.

The second method calculates the "internal rate of return" (IRR) of a project. This is done by computing a hypothetical discount rate that would equalize costs and benefits, thus yielding $NPV_{IRR} = 0$. The internal rate of return is compared with the discount rate – if the internal rate

[5] KSh = Kenyan Shillings. For reasons of simplicity, all monetary values are expressed in local currency. In July 2000, 1 US $ equaled approximately 75 KSh.

of return exceeds the discount rate, the project is profitable and should be accepted. In the example above, NPV would be zero if the discount rate were 120% (rendering the anticipated 110 KSh after one year equal to 50 KSh at present time, thereby exactly offsetting the costs). Since the internal rate of return (120%) is by far greater than the discount rate of 10%, the project is again rated profitable. In mathematical terms, choose r in the equation above, so that

$$\sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t} = 0.$$

The third method is to divide the discounted costs by the discounted benefits, obtaining a "benefit-cost ratio" (BCR). If the ratio is greater than 1, the benefits exceed the costs and the project is accepted (JORDAN 1998).

Again applying this to the example above, anticipated benefits of 100 KSh (having used a discount rate of 10%) are divided by costs of 50 KSh, resulting in a benefit-cost ratio of 2. The project is again accepted. The general formula for the benefit-cost ratio is

$$Benefit\text{-}cost\ ratio = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}}$$

In this study, we compute all three decision criteria, since each indicator yields specific information beyond deciding about whether to accept a project or not. The net present value criterion gives an indication of the size of the project and the magnitude of the profits that can be expected from it. The internal rate of return and the benefit-cost ratio criteria are relative measures of profitability and enable a comparison of projects of different scales. The IRR criterion indicates how fast benefits are realized and allows to see how the choice of a discount rate influences the profitability of the project.

2.2.3 Determination of the breakeven point

If a project is profitable, a breakeven analysis can provide additional information. The breakeven analysis tracks the cumulative costs and benefits as the project progresses. The breakeven point is the point in time where

$$benefits = costs.$$

In most projects with initial investment, the benefits eventually surpass the costs. The breakeven point indicates how long it takes until the project reaches the net income area. Breakeven analyses can be carried out with and without discounting (MISHAN 1988) to show the effects of the interest rate applied (Fig. 2.1). A graphic breakeven analysis also points to the investments required by the investigated project. Even though a project may be beneficial in the long run, high investment costs may make it prohibitive.

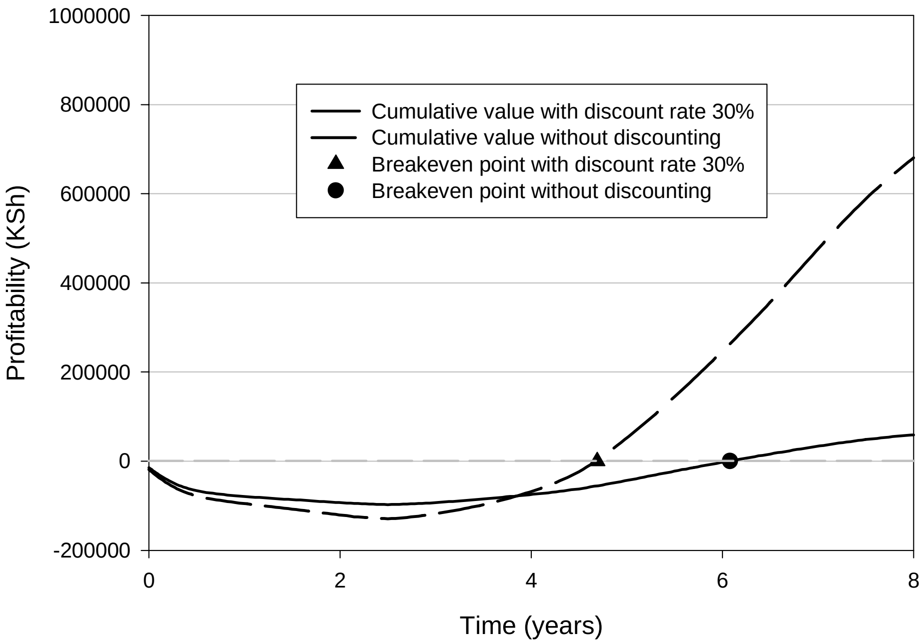


Fig. 2.1 Example of a graphic breakeven analysis. The solid line indicates the cumulative value when a discount rate of 30% is applied, the dashed line shows the same project without discounting. The breakeven point is reached earlier if the discount rate is zero.

2.2.4 Sensitivity analysis

Cost-benefit analysis renders one single variable with a final recommendation whether to engage in a project or not. The disadvantage is that this variable does not reveal the critical factors which contribute to its formation – in other words why a project is accepted or rejected. A sensitivity analysis examines the response of the decision criteria to changes in the input parameters. In cost-benefit studies, the sensitivity analysis performs the task of evaluating how the final result relates to the input factors that enter the calculations.

There are different ways to carry out a sensitivity analysis. A statistical method is to compute a probability distribution for the decision criteria. In our case, probability data for the input parameters were not available, therefore an empirical approach was chosen.

In this study, a single-factor sensitivity analysis examined the response of cost-benefit ratio to variations in each individual input parameter. Compiling the results in a matrix enabled a comparison of the input variables. A multi-factor sensitivity analysis repeated the calculation with all factors simultaneously being shifted towards either increasing or decreasing profitability. To display the result, the cost-benefit ratio was plotted against the percentage of deviation of all factors from their respective base value (Fig. 2.2).

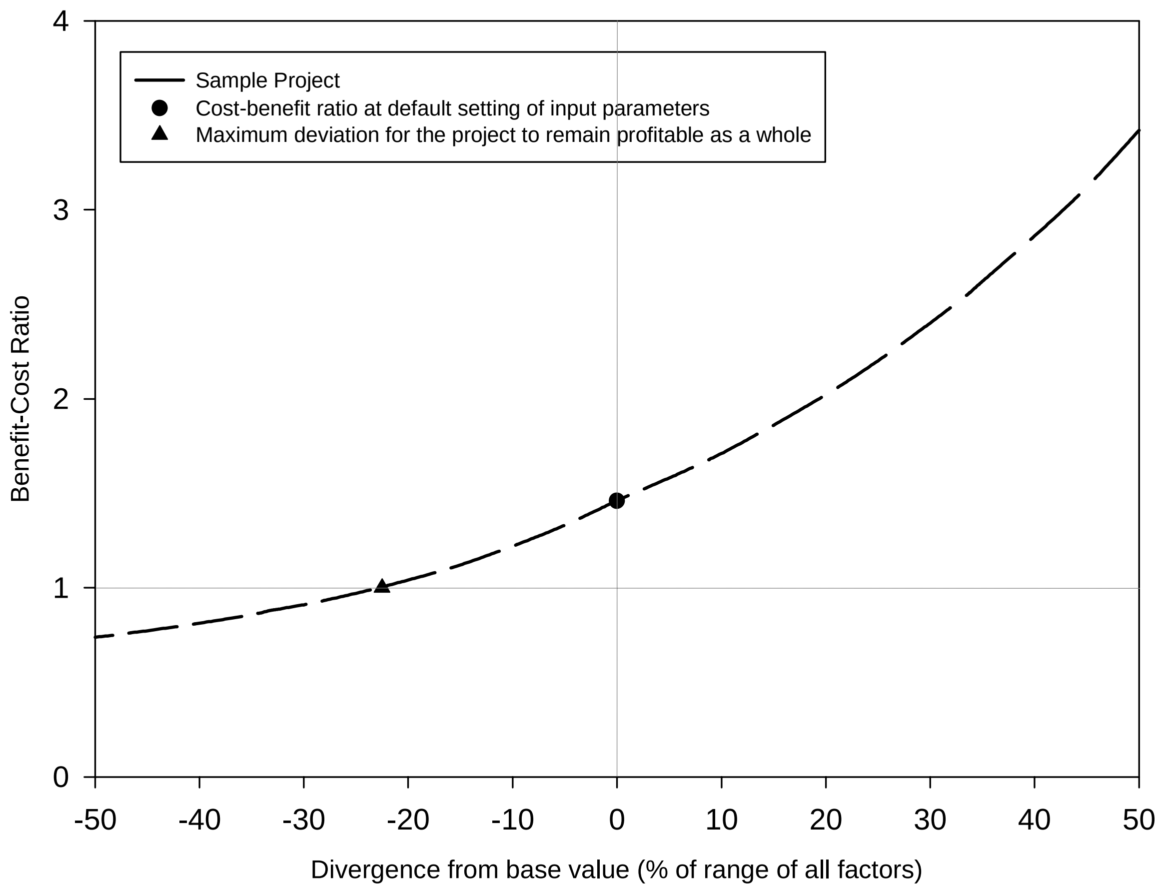


Fig.2.2 Example of a multi-factor sensitivity analysis. The line indicates the change in benefit-cost ratio in response to a simultaneous variation of all input parameters.

2.3 Data collection and methodology

Most of the fieldwork was conducted in Kakuma, northern Kenya (34° 51' East and 3° 43' North). Different techniques were used to obtain relevant data for the analysis. Wherever possible, direct measurements complemented information gathered in local surveys. A casuistic approach was chosen for interviews with Turkana, questioning a limited number of key informants. A survey of 19 people was conducted on the subject of time preference and hypothetical labor costs (willingness to work).

The data for irrigation structures were based on the "Greenbelt"-concept of the GTZ RESCUE project in Kakuma and a scientific research project (LEHMANN 1998) conducted in 1994-1996. Where necessary, simple ecological modeling was used to generate operational data for the irrigation systems. Climatological data of Kakuma (LEHMANN 1997 and DROPPELMANN, 1999) and the FAO-Penman-Monteith methodology (ALLEN et al. 1998) were used to estimate crop water requirements (compare chapter 3.5.1).

Input data for the cost-benefit calculations were gathered from surveys. Working time for building micro-catchments was measured, using additional literature data (REIJ et al. 1998) to elaborate the relationship between bund size and construction time (compare annex 2). Labor costs were estimated using surveys as well as work incentives paid by aid agencies to the local population. Construction costs for the macro-catchment scenario were calculated based on actual expenses for a prototype built in 1994 (LEHMANN, pers. comm.). Prices of seedling production were researched in Dadaab refugee camp in a private tree nursery project (BENICKE, unpubl. data).

Local yield data from small-scale plantations in the refugee camp was aggregated with records on fruit tree yields in Kenya and other tropical regions (MORTON 1987, AIC 1984, VAN EA 1992, WESSELER 1996).

The total market volume of the fruit market was obtained by interviewing all traders (both refugees and Kenyans) that procured fruit from outside of Kakuma. Prices for fruits were observed over a time span of two months. Average sale prices were used in combination with yield data to estimate the monetary benefits derived from selling the produce of the three species of fruit trees concerned in this study (compare chapter 3.3.9). Sale prices of tools and other equipment were researched locally. Discount rates and the project time horizon were estimated based on local surveys, literature data and aid agency information (see chapters 3.3.11 and 3.3.12).

Chapter 3

Baseline Data for Analysis

3.1 Introduction

In this chapter, we outline the data necessary for carrying out the cost-benefit calculations. The information presented here takes the role of an "intermediate result". It represents an outcome from the field research, but enters the decision criteria through a number of input parameters. Some of these parameters are required in all of the scenarios considered, while others are attributed to one particular scenario. In their entirety, the baseline data reflect the local conditions of Kakuma. The parameters are delineated as follows:

- The target group to implement the irrigation project and their access to land
- The costs of labor required by the project
- The costs of water necessary to sustain the seedlings during the first growth stages
- The costs of the tree seedlings to be planted in the irrigation systems
- The number of seedlings planted simultaneously
- The survival rate of the trees
- The tree management techniques used
- The guarding of the plots, protecting them from livestock or thievery
- The yield expected from the trees planted in the system
- The costs of selling the produce on the local market
- The discount rate applied to all costs and benefits arising in the course of the project
- The time horizon of the project

Chapter 3.3 discusses the parameters in detail. The extent to which these factors[6] contribute to the final result depends on the irrigation system that is used. Chapter 3.4 outlines the two

[6] In this study, the terms "input parameter" and "input factor" are used interchangeably.

scenarios considered in this study. Chapter 3.5 elaborates the micro-catchment scenario, while Chapter 3.6 deals with the macro-catchment approach. Chapter 3.7 briefly describes the traditional sorghum agriculture of the Turkana, which serves as a reference scenario. The subsequent chapter makes some general considerations with regard to how the data is organized in this study.

3.2 Organization of the data

For each aspect of the baseline data, information from various sources was taken into account (chapter 2.3). Despite this variety, it is necessary to have a defined value for calculating the decision criteria (chapter 2.2.3). A sensitivity analysis (chapter 2.2.4) allows to investigate the effects of data variability, but still it is necessary to find one value that serves as a basis for analysis. The difficulty with regard to the variety of information sources is that one has to be cautious with applying statistical tools. Theoretically, averaging all available data would be possible where quantitative information is present. In most cases however, this would not lead to a sensible and "correct" result.

The following example tries to illustrate the situation. On its own, information on salary levels of an aid agency in Kakuma is a valuable indication of how much it would cost to hire people building irrigation structures. The same is true for asking individual persons about how much money they would demand for performing such a task. However, merging these two pieces of information is problematic. First, the agency salary may apply to a number of people, not just one individual. Second, the agency may pay a "fair" salary as opposed to a salary resulting from the supply and demand situation on the labor market.[7] Third, that individual may or may not have access to that salary as an alternative to working in an irrigation project.

This work approaches the problem by presenting data organized by data source. Standard values[8] and alternatives investigated in the sensitivity analysis are then chosen on the basis of a qualified estimate.

[7] This is a realistic assumption, as most jobs with international agencies are much sought-after with many applicants for each vacant position (compare table 3.1).

[8] The term "standard value" is subsequently used to indicate the value that serves as the basis for calculation of the decision criteria (as opposed to alternatives applied in the sensitivity analysis)

3.3 General data

This chapter examines those input parameters that influence the decision criteria of the project irrespective of the particular scenario applied. The data covered here embrace the local situation of Kakuma and provide the framework for a local fruit tree plantation.

3.3.1 Target group and land availability

As mentioned in chapter 1.3, the refugees in Kakuma are not allowed to utilize land outside the borders of the camp. The importance of land for the local Turkana has led to resistance against the usual practice to allow refugees access to the area surrounding the camp and its resources. In contrast to other East African countries (and even in contrast to Dadaab[9], the second refugee camp in Kenya), refugees must buy all resources not provided by the aid agencies from the Turkana. Therefore, while runoff farming in general would be an option for refugees as well as for the local population, in Kakuma only the Turkana have access to land. For them, the main constraint is the suitability of land for irrigation purposes. Micro-catchments require uniform surfaces of a slope between 1 and 8%, depending on the system that is used. A macro-catchment system must be located next to an intermittent channel from which the irrigation water can be diverted.

For the purpose of our analysis, we assume that Turkana are implementing the irrigation systems, considering the possibility of refugees being allowed to set up such structures in the sensitivity analysis.

3.3.2 Costs of labor

The profitability of any project depends on the costs that are accrued for labor. Labor costs are the monetary equivalent of the working time necessary to perform the activities of the project. In a fruit tree plantation under runoff irrigation, working time has to be used among other tasks for constructing catchments, fencing the site, planting and managing the trees, and for selling the produce. Spending time working for a certain project implies loosing this time for other possible activities, and the benefits foregone in this way are the "opportunity costs of

[9] Occasionally in this study, reference is made to Dadaab refugee camp. Dadaab is located in eastern Kenya near the border to Somalia and hosts mainly Somali refugees. The climate is similar to Kakuma.

labor".[10] In this study, working time was assigned a monetary value on the basis of what people were being paid for alternative forms of work, either self-employed or working for others. This approach is based on the assumption that people will only engage in a project if their salary is comparable to what they can otherwise earn on the local labor market.

In Kakuma, the employment income varies according to the type of work, qualification, employer and background (refugee or Turkana) of a person (table 3.1). The few Turkana who work for aid agencies are usually paid a higher salary than their refugee counterparts, because the they do not receive goods and services as humanitarian assistance. However, in all other forms of employment, the Turkana derive a consistently lower income from their working time than the refugees.

Physically demanding work is paid at a higher rate than light work. This may be a general property of rural labor markets, but in Kakuma the harsh physical environment clearly plays a role. Workers with special qualifications, such as agriculturists, are also paid more. On the other side, child labor is valued at a cheaper rate. For the purpose of this study, we apply a salary of 55 KSh for Turkana and 85 KSh for Refugees[11]. The salary is doubled for physically demanding tasks (such as moving earth for the construction of bunds) and halved for small children[12]. Wages for experts capable of supervising the construction of the macro-catchment system are calculated on a basis of 350 KSh per manday (LEHMANN, pers. comm.).

For the scenario analysis, the standard wages outlined above are doubled and halved, depicting a sensible upper and lower boundary for this input parameter.

[10] The concept of opportunity costs describes the fact that decisions in a world of scarcity always imply giving up something else. Economic costs must take these alternatives into account. The opportunity cost is defined as "the value of the good or service forgone" when taking a certain decision (SAMUELSON & NORDHAUS, 1998). Even if people apparently have plenty of "spare time" (as it is the case in the project area), the payment for the time spent in the project must exceed the perceived value people derive from their leisure time.

[11] The values are chosen based on the range of wages given in table 3.1 and are not statistically calculated (see the introductory remarks in chapter 3.2)

[12] In the traditional agriculture of the Turkana, children scare off birds during the ripening stage of the sorghum plants. In the water harvesting scenarios, child labor does not play a role.

Table 3.1 Costs of labor in Kakuma, northern Kenya; type of work and range of salary for different tasks (interquartile range and median, n_{total} = 85); average values for all work types, subdivided into refugees and Turkana; various information sources

Type of work	Wage per manday [KSh][13]			
	Turkana		Refugees	
	Range	Median	Range	Median
Salaries and incentives[14] paid by NGOs for work in their respective projects	85 – 285	154	60 – 133	94
Street sellers and shop keepers	4 – 87	48	15 – 800	75
Other forms of self-employment (Biketaxi, gathering firewood, ...)	40 – 180	64	40 – 178	89
Hired labor (Building jobs, household help, ...)	13 – 245	48	50 – 133	83
Willingness to work[15]	40 – 225	80	30 – 300	100

3.3.3 Costs of water

It is likely that after planting, immature trees require to be watered for some time until their root system is established (LEHMANN, pers. comm.). Thereafter, the tree should be able to fulfill its demand with water supplied by the irrigation system. The period during which supplementary watering is necessary may vary, depending on rainfall patterns, tree species and soil type. The best planting time for the tree seedlings is after the first or second heavy rainstorm of the long rains, providing the seedlings with sufficient, if not excessive water. The most critical period occurs during the dry months after the first rainy season, when the top soil

[13] The remuneration for the different kinds of work varies considerably. Most notably, a very narrow percentage of the people living in the Kakuma have far higher incomes than the majority of the population. Since those people would not necessarily be targeted by the project, taking the interquartile range and the median to indicate range and average level of payments appears justified.

[14] An incentive is an allowance given for supposedly voluntary work by agencies. For the purpose of this study, the difference is negligible, as the amount paid is not a supplementary income, but represents a fully competitive salary.

[15] People were interviewed about how much they would have to be paid to work for one day (see annex 4).

dries up. At the same time, the roots of the young trees have not yet grown far enough into the subsoil. Watering is likely to be necessary at least for some weeks, perhaps for the duration of the entire first dry season.

In the refugee camp, water is provided by the aid agencies[16]. The Turkana do not have access to this water, instead they dig wells into the dry river bed of the seasonal river Tarach, where groundwater is reached at a few meters depth. The Turkana use this traditional way of obtaining water both for their own consumption and for income generation by selling it.

To obtain a price for water, we consider the working time that Turkana require to fetch the water from the river. How much time is needed depends on the distance between the river and the irrigation system. For simplicity, we apply the average time for the Turkana to fetch water for their household purposes, which is roughly 0.8 manhours or 5.3 KSh per jerrycan of 20 liters. For the purpose of sensitivity analysis, we outline three possible sub-scenarios:

a) No supplementary watering is necessary
b) Seedlings are watered with 10 liters[17] per tree and day over a period of 2 months (beginning 1 month after planting)
c) Same as b), thereafter the seedlings are watered with 20 liters per tree and day until 7 months after planting

We use the above labor cost as the price per jerrycan, assuming that the water itself is can be freely fetched from the river.

[16] The UN and its implementing partners have sunk several boreholes up to 60m deep into the soil, where they retrieve water from confined aquifers running along geologic faults of the Rift Valley.

[17] The amount of water necessary to irrigate the seedlings is derived from farmer's experience in the refugee camp and from experiments conducted with seedlings of papaya, guava and mango (BLOEMERTZ, unpubl. data).

3.3.4 Costs of seedling production

The usual method of raising fruit trees is to cultivate them in a nursery (typically 3-6 months) until they reach a size that allows transplanting them into the actual farm. The treatment of the seedlings in the nursery influences both their later survival rate in the field and the point in time when the trees start bearing fruit. Grafting and budding techniques can enhance the quality of the young seedlings (ITFSP, 2000).

Kenya has a large number of commercial and semi-commercial tree nurseries, many of them prison farms that use forced labor to cultivate the seedlings. In the Turkana district there are very few nurseries. Alternatively, the establishment of small-scale private nurseries would be an option in order to supply seedlings for the plantation. Table 3.2 compares the prices per seedling for both possibilities.

This study uses the costs of local seedling production as standard value (as it seems the more logical option), considering the sale prices of commercial nurseries in the sensitivity analysis.

Table 3.2 Prices for mango, guava and papaya seedlings in Kenya; data taken from URMAYA (1997) and a project of private tree nurseries in Dadaab (BENICKE, unpubl. data);

Type of seedling production	Species	Range of costs (in KSh per seedling)	
		Range	Average
Production of fruit tree seedlings in a local tree nursery under commercial conditions[18]	Mango	9 – 24	15
	Guava	4 – 18	9
	Papaya	4 – 18	9
Sale prices of commercial nurseries in Kenya	Mango	10 – 70	30
	Guava	10 – 40	20
	Papaya	4 – 30	13

[18] "Commercial conditions" means that the input would not be supplied freely from any agencies.

3.3.5 Number of seedlings planted

The initial growth stage is crucial for the survival of the trees. It is recommendable to plant several tree seedlings into each space devoted to one mature tree. This is to ensure that at least one seedling survives in each of the spaces. The seedlings have a much lower water requirement than mature trees, therefore they will not compete for soil water amongst each other. After some time, surplus seedlings are removed until the intended number of trees are left.

In the scenarios below, we assume that two seedlings are planted simultaneously, with one and three seedlings considered in the sensitivity analysis.

3.3.6 Survival rate

Over the course of the project, it is unlikely that all trees that survived initially also come to produce maximum yields. Pest infestation, prolonged periods of drought, lack of nutrients, wind, and even excessive harvests may all harm and eventually destroy some trees[19]. Good management techniques have shown to significantly improve the survival of these trees, yet a 100% success rate appears unlikely. If a tree dies shortly after planting, it can be replanted without much financial loss – at a later stage, the effect is more severe.

It is difficult to predict the loss that a farmer is likely to incur as a result of the problems mentioned above. For simplicity, an overall survival rate of 80%[20] is assumed, a success rate achieved under comparable climatic conditions for native species in micro-catchments in Dadaab refugee camp. For the sensitivity analysis, we apply a survival rate of 60% and 95%.

3.3.7 Tree management

Relatively little is known about the management requirements of fruit trees in runoff irrigation systems. Fruit trees grown in the refugee camp showed that both the application of fertilizer and insect deterrent increases the survival rate and improves harvest yields.

Lacking chemical fertilizer and pesticides, several improvised techniques have been used in local agriculture. One refugee farmer applied both manure and ash to fruit trees grown in his

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[19] For example, most of the papayas planted in Kakuma so far have had severe problems with termites and other diseases

[20] “Survival rate 80%” means that from 80% of the trees, the yield according to the data given in chapter 3.3.9 is assumed. 20% of the trees die or bear no fruit at all.

homestead. The ash serves as a deterrent against termites while the manure acts as an organic fertilizer providing nutrients to the tree. Both the ash and the manure are incorporated by tilling the soil and adding water. The advantage of this method is that both components are free and readily available in Kakuma.

In the absence of other data applicable to the local conditions, this method serves as a role model for the management of the trees in the scenarios outlined below. For the sensitivity analysis, the costs for tree management are halved and doubled.

3.3.8 Guarding the plots

After planting the trees, it is necessary to guard the sites against livestock. Large numbers of sheep and goats roaming around freely in search of fodder are the main concern. For good reason, the Turkana fence their traditional sorghum gardens with thick branches of thorn bushes (mainly *Prosopis*). Despite this measure, once the sorghum has germinated, watchmen oversee the sites 24 hours a day. A single goat slipping through a small hole would be capable of devastating an entire plantation.

At least during the first year (8 months for papaya), total supervision is considered to be necessary for the fruit trees as well. After that time, guarding the trees during daylight hours (12 hours per day) is sufficient. Only after the trees have grown out of reach of the livestock (papaya after 1 year, mango and guava after 3 years), the natural fence is assumed to offer sufficient protection. In a small plantation with few trees, all management duties can be performed by a single caretaker who also takes over the role as a watchman[21].

Another problem arises with regard to the fruiting trees. Among the Turkana, livestock raiding has a long tradition[22], and it may well be necessary to resume guarding the plots when the trees start to bear fruit. We consider the economic consequences of such a step in the sensitivity analysis.

[21] The only possibility to omit watchmen entirely during the first stages of the project would be to guarantee that no livestock can enter the plots with the fruit trees. This could be achieved by erecting a mash-wire fence protecting the trees. However, it turned out that in Kakuma, guards were necessary to safeguard the fence itself against thievery. Therefore, erecting a natural fence and guarding the plots appears to be the only feasible approach.

[22] In the Turkana society, livestock raiding functions as a means of redistribution of livestock between the more wealthy and the poorer livestock owners. Tribe members who have lost livestock due to environmental hazard will raid other Turkana and either die in the attempt or be able to restock their herd with the captured animals.

3.3.9 Yield data

Benefits from fruit trees occur mainly from the fruit harvest[23]. Very few fruit trees had been planted in Kakuma at the time of this study, and quantitative data on yields were limited. Therefore, data from locations in Kenya and other tropical regions were combined with local fruit prices to estimate harvest benefits.

The lack of local data raises the question whether irrigated fruit trees in arid areas can produce yields similar to the wetter places where they are commonly planted. Here, relatively little is known to date. On one hand, high day temperatures foster rapid growth and increased production. However, nutrient depletion of the soil and periodic water stress can be significant constraints. Evidence suggests that with proper management, fruit trees can do fairly well. Yields from a small number of papayas planted in Kakuma and Dadaab were rather above than below average expectation. Still, the yield data given here can only serve as a rough indicator of exact values, not the least because nursery practices, choice of cultivars and management techniques all influence the yields.

Table 3.3 shows average values of yield data concerning the three species dealt with here[24]. It can be seen that papayas are fast growing species that yield rapid benefits, but need to be replanted after 3-4 years. In contrast, mango takes 2-3 years before the first harvest can be expected, but the yield constantly increases as the tree grows. Guava takes an intermediate position with regard to harvests.

For the sensitivity analysis, it was assumed that the income derived from the harvests ranges between 50% and 200% of the values given in table 3.3.

[23] Other advantages of trees including shade, wind shelter, protection against erosion and firewood (and these benefits may play a role on a homestead fruit orchard), but these benefits are small compared to the income generated by selling the fruits

[24] See annex 1 for details.

Table 3.3 Average monetary value of yield expectations for papaya, guava and mango; various sources; monetary value derived from local prices in Kakuma. See annex 1 for details.

Year after planting	Yield value (in KSh per tree and year)		
	Papaya	Guava	Mango
1	0	0	0
2	2577	200	0
3	2297	343	204
4	1921	990	1483
5	1440	2774	2514
6	720	3275	4311
7	360	3275	5378
8	180	3275	5868
9	90	3275	5868
10 and more	90	3275	5868

3.3.10 Selling the produce

A major prerequisite for the feasibility of a fruit tree plantation in Kakuma is the presence of a market where the harvest can be sold. Moreover, the market determines sale prices and turnover rates.

Fruit is sold both in the refugee camp and the town of Kakuma. At the present time, most of the fruit is imported from the Kitale area (410 kilometers away), with some traders even procuring the produce from south of Nairobi (about 800 kilometers distance). Table 3.4 gives an overview of the monthly turnover of fruit in Kakuma.

Most fruit (probably more than 90%) is consumed by refugees, as the majority of them comes from places where fruit constitutes part of their everyday diet. With the United Nations supplying only basic food, those refugees who can afford it buy fruit and vegetables to improve their nutrition. The Turkana also eat fruit, even though the species sold in Kakuma do not grow naturally in the district. Although most Turkana lack the money to afford fruit, those earning a regular income also buy fruit from the market.

Table 3.4 Monthly turnover of fruit in Kakuma, northern Kenya. Source: author's own data (26 traders procuring fruit from outside Kakuma).

Type of fruit	Monthly turnover [KSh]
Banana	878,000
Mango	604,000
Orange	458,000
Lemon	208,000
Passion fruit	136,000
Pineapple	87,000
Papaya	21,000
Total	2,392,000

The market demand for fruit is high. Each month, every refugee family of 4 to 5 people spends an average of 166 KSh on fruit. Selling fruit and vegetables in the camp is a lucrative business. Some refugees have started to procure these goods from outside the camp themselves, even though this implies having to pay a substantial "fee" at police roadblocks, as free travel is not permitted.

In summary, Kakuma offers a substantial market for fruit, with refugees accounting for the most important customer group. From this point of view, producing fruit in water harvesting systems would be capable of generating revenues.

For the cost-benefit analysis, an estimate is required on how much working time it will take to sell the fruit produced in the plantation. Kakuma has a total of 26 traders procuring fruit from outside Kakuma, selling directly to customers as well as to small-scale retail traders. For each fruit type, the average time required to sell a certain value can be derived from the total sales per month as given above. Mangoes sell at an average rate of 774 KSh per day on the local market. For papaya and guava (the other fruits produced in our scenarios), sales have to be estimated. At present time, these fruits are rarely sold in Kakuma, not due to lacking demand but because they get spoiled too easily during the transport. For reasons of simplification, we assume the same selling rate as for mango.

3.3.11 Discount rate

As outlined in chapter 2.2.2, all costs and benefits have to be discounted to their present value in order to allow the comparison of net benefits and net costs of the project. The fruit tree plantation requires a certain investment (both at initial and later stages of the project) and the capital[25] foregone in this way has to bear interest in order to render the project profitable.
The "opportunity cost of capital" concept (DIXON et al. 1989) uses an analogous idea as outlined above with respect to labor. If capital is available, the use of this capital for the project has to be compared against the alternative uses. If capital is not available, interest rates for borrowing a necessary amount should be applied taking the local conditions into account.
Additionally, the discount rate has to reflect the risks and uncertainties attached to the engagement in a long-term project. Therefore, a "risk premium" is added to the interest rate derived from the opportunity cost of capital. In particular, this premium covers the following aspects:

- The risk to adopt a new technique that does not bring the expected results
- The uncertainty concerning the personal situation over the time of the project
- The risk of suffering until the benefits materialize

In a developed society where people face a secure future, basic needs are covered, and credit is easily available, the risk premium will be close to zero. In a rural economy however, with abundant poverty, insecurity towards the future and limited access to formal credit mechanisms, risk will have a considerable impact on decision making. Taking the credit sector as an example, no commercial bank would give a loan to a destitute farmer, even if the expected returns from his endeavor allow repayment of the loan. Therefore,

$$Discount\ rate = interest\ rate_{\ OCC} + risk\ \ premium$$

with $interest\ rate_{\ OCC}$ representing the opportunity costs of capital. The next step is to examine the two factors in the context of the local situation.

25 In this context, the term "invested capital" comprises all costs necessitated by the project. Therefore, capital investment can occur in form of manual labor or financial capital.

a) Opportunity costs of capital

For the Turkana, the best approximation to opportunity costs of capital is to look at herd growth rates of livestock. As the entire system of values of the Turkana is based on animals, ODEGI-AWUONDO (1990) notes that livestock acts as a traditional form of "bank account". In fact, it is not uncommon for Turkana to buy livestock for money they have earned, as they expect a high return on this "investment" (BEST 1981). Livestock can also be sold on the local market to finance other necessary expenditures. Therefore, it is possible to obtain an interest rate by calculating returns from pastoral production. If runoff irrigation offers lower rates of return than what the Turkana expect from their livestock, it is unlikely that they would invest in this technique.

Alternatively, commercial lending rates in Kenya are between 27% and 35% (inflation already accounted for), but the Turkana would hardly qualify for a formal credit from a Kenyan bank. In the refugee camp, an aid agency runs a microcredit[26]-program, charging an effective interest rate of only 19%. At the moment, these credits are issued only to refugees and only on a short-term basis, but plans are to extend the program to the Turkana living in the area (IRC, pers. comm.). Table 3.5 compiles the findings for the opportunity costs of capital. Taken together, an opportunity cost of capital between 20% and 30% seems appropriate.

[26] A microcredit program is a program that issues small loans for business undertakings in developing countries. Its basic idea is to use circumvent the problem of lacking collateral by putting together groups of at least 5 people who collectively stand in for each member's loans. Microcredit programs have been very successful for example in Bangladesh, where they became known as "Grameen Banks".

Table 3.5 Opportunity costs of capital applicable for Kakuma, northern Kenya; type and range of interest rate. Inflation rate = 5%, herd growth calculations include the invested labor. For details of the calculations, see annex 3

Type of interest rate	Range of interest rate	
	Range	Average
Estimates in herd growth by Turkana	26% - 61%	45%
Herd growth calculated from (LITTLE & LESLIE 1999)	22% - 33%	26%
Herd growth given in (RUNGE 1998)		32%
Commercial money lending rates in Kenya[27]	27% - 35%	31%
Microcredit program in the refugee camp		19%

b) Risk premium

Challenged by the environmental conditions of their arid home, risk and uncertainty are dominant factors in the life of every Turkana. The necessity to take advantage of resources as they appear both in space and time forced them to develop an extremely opportunistic way of life. Despite the national government aiming for integration of the district, Turkana remains isolated from the Kenyan society. Infrastructure is still underdeveloped, self-employment plays an important role and a social safety net is not in place.

The perception of risk can be seen from the results of an interview where 19 inhabitants of Kakuma were questioned on their subjective time preference. Asked what "their" interest rate would be if they lent money to somebody, respondents gave interest rates between 7% and 305% with a median of 100%. Theoretically, this would result in a risk premium of 70-80% or more, although such surveys have to be interpreted with caution (STREET 1990).

A conservative estimate for a risk premium of 10-20% yields a total discount rate of 30-50%. This rate is high compared to other case studies where discount rates between 5% and 30% have been applied (DIXON et al. 1990, NELSON et al. 1998).

[27] Inflation in Kenya in 1999 was 3.5%; due to the drought in 2000, inflation was expected to rise. An inflation rate of 5% was included into the above values.

For the purpose of our analysis, all costs and benefits are discounted with a base rate of 30%, using 20% and 50% in the sensitivity analysis. This takes into account both the difficulties in finding a “correct” discount rate and possible changes in the factors determining the rate. For example, overgrazing can deteriorate the prospects for livestock development and subsequently lower the opportunity costs of capital. Alternatively, better government services can reduce uncertainty and thereby also contribute to a lower discount rate.

3.3.12 Time horizon

Generally, once the irrigation structures are set up, it is possible to maintain them over a long period of time. Fruit trees like mango can deliver fruit for several decades, with yields only slightly decreasing with age. However, several restrictions warrant the application of a time horizon in this study:

1. The macroclimate of the study area is highly variable, with severe droughts (possibly lasting more than a single year) occuring every 10-20 years (LITTLE & LESLIE 1999 and EKENO pers. comm.). Such a drought is likely to have a devastating effect on any perennial agricultural set-up depending on continuous supply of water.

2. The importance of Kakuma as a settlement derives from the refugee camp which was set up in 1990 and has been growing ever since. Along with the expansion of the camp, more and more Turkana were attracted by opportunities for income generation and the presence of the aid agencies servicing the refugees (see chapter 1.3). Without the refugee camp, Kakuma would lose its importance as a center of economic activity in the district and the local market is likely to collapse. The market for fruit depends on the presence of the refugees, and the same is true for the feasibility of producing fruit commercially in Kakuma.
   As the civil war in Sudan has been going on for 20 years, it is not foreseeable that the problems causing the refugee influx will be solved in the near future. On the other hand, it is part of the mission of UNHCR to contribute to resolving the refugee crisis in the region and ultimately repatriate people to their home countries (UNHCR, 2001). All in all, predicting how long the camp will exist is difficult.

Due to both factors, it is sensible to apply a time horizon to our analysis. For the purpose of this work, we consider those costs and benefits occurring during the first 15 years of the project. An alternative time horizon of 10 years is used in the sensitivity analysis.

3.4 Outline of the scenarios – the framework for analysis

After having dealt with general considerations of planting fruit trees in Kakuma, we now turn to the irrigation systems. Choosing a an irrigation approach has to take several aspects into account. The most important questions are (1) the question of scale combined with the availability of necessary resources, and (2) the question which project phases are dealt with in the cost-benefit calculations.
We discuss briefly both aspects and outline two different scenarios for setting up an irrigation structure. Finally, traditional rainfed sorghum cultivation provides a "reference scenario" for comparison.

3.4.1 Project scale

As mentioned in Chapter 1.4, runoff irrigation systems can range from micro-catchments to large-scale irrigation schemes. The question of scale is important, since it determines the resources necessary to execute the project. A dividing line can be drawn between projects that require mainly manual labor and those using machinery. Embarking on a small-scale approach is a way to minimize risk and draw upon resources that are locally accessible. Manual labor is available in large quantities, therefore the project is constrained only by the local alternatives for income generation. On the other side, embarking on a large-scale project usually implies significant initial investment. The factor of risk and the availability of financial capital may limit the feasibility of such a project.

3.4.2 Project boundaries

The project discussed in this study encompasses several phases. First of all, people have to be trained on surveying, irrigation techniques and fruit tree management. The next phase consists of erecting the necessary structures and planting the seedlings. Finally, the maintenance phase encompasses management of the site and the trees, as well as selling the harvested fruit.
The important question concerning cost-benefit calculations is which of these stages should be considered part of the actual project. In general, it is possible to consider only the maintenance of a project as opposed to its full implementation. Frequently in development projects, certain structures are set up, participants are taught how to preserve them, and the project is then left to its beneficiaries. However, as noted before, projects should be self-sustainable (including economically viability) without initial financing from the outside.

Therefore, this study includes the whole process of setting up the necessary structures as well as maintaining them. We assume, however, that knowledge of the basic techniques of water harvesting is already present[28]. The appropriate point of view for this analysis is that of local Turkana who have learned about runoff farming and decide (on economic grounds) whether to implement these techniques.

3.4.3 Outline of different scenarios

We calculate two different scenarios for planting fruit trees in Kakuma. The scenarios are hypothetical, but each has a local "role model", meaning that the respective approach was tested in a certain form by either a development agency or a scientific project. These role models provide the framework for the cost-benefit analysis. Extending and modifying them allows to provide a comparative evaluation of farmer's options to adopt fruit tree planting in Kakuma. The scenarios are delineated as follows:

1. Planting of fruit trees in a 3-hectare water harvesting system of micro-catchments, each catchment individually designed to accommodate one fruit tree and to fit its water requirements. This approach is tried in the "Greenbelt concept" of GTZ Kakuma. Although the GTZ sites were set up for reforestation purposes, it would be possible to dimension these structures to accommodate fruit trees as well. Chapter 3.5 outlines this scenario.

2. Planting of fruit trees in a 3-hectare macro-catchment water harvesting system, using a number of large basins accommodating all fruit trees. This system was built by a research project (LEHMANN 1998) in 1994 and proved its ecological viability for a variety of species, including fruit trees. Chapter 3.6 describes this scenario in detail.

The first scenario requires only manual labor and little capital expenditures (mainly for tools and seedlings). The structures for the macro-catchment system have to be prepared by an excavator, necessitating capital expenditures of approximately KSh 435,000. Within each scenario, a sensitivity analysis (compare chapter 2.2.4) is conducted.
With regard to size, a plantation encompassing three hectares is assumed for each scenario. Using larger areas would meet both ecological (compare chapter 3.3.1) and socioeconomic

[28] In Kakuma, the GTZ MLP RESCUE project provides such training and aims to deliver understanding to the local population about agriculture and tree planting.

constraints. Although land is commonly owned in Turkana, land use rights are usually given for plots no more than a few hectares in size. In order to produce the same amount of fruit as a 3-hectare macro-catchment system, a micro-catchment scheme would require an area of 52 hectares.

In each of the systems, three different species of fruit trees are investigated (mango, guava and papaya) to enable comparison of slow-growing versus fast-growing species[29]. Finally, the scenarios are compared against the rainfed sorghum plantations of the Turkana, the traditionally evolved agricultural system in the area.

The following chapters detail a description of these scenarios.

[29] For a short description of these species, see Annex 1.

3.5 Micro-catchment scenario

In this scenario, it is assumed that the fruit trees are planted into semi-circular bunds, simple micro-catchments that consist of a half moon shaped earth wall that retains the runoff generated from the surface area directly above the semi-circular enclosure. At the base of the bund, a single tree is planted that supposedly benefits from the entire water within the catchment (see Figure 3.1).

The area inside the bunds, where the trees are planted, is called *crop area* (or *runon area*), the space between the bunds (from where the water is harvested) is called *catchment area* (or *runoff area*). The measurements of the whole system are geared to fulfill the water requirements of the respective tree and eventually determine how many trees can be planted on a given area. In the chapters below, the calculations are conducted stepwise.

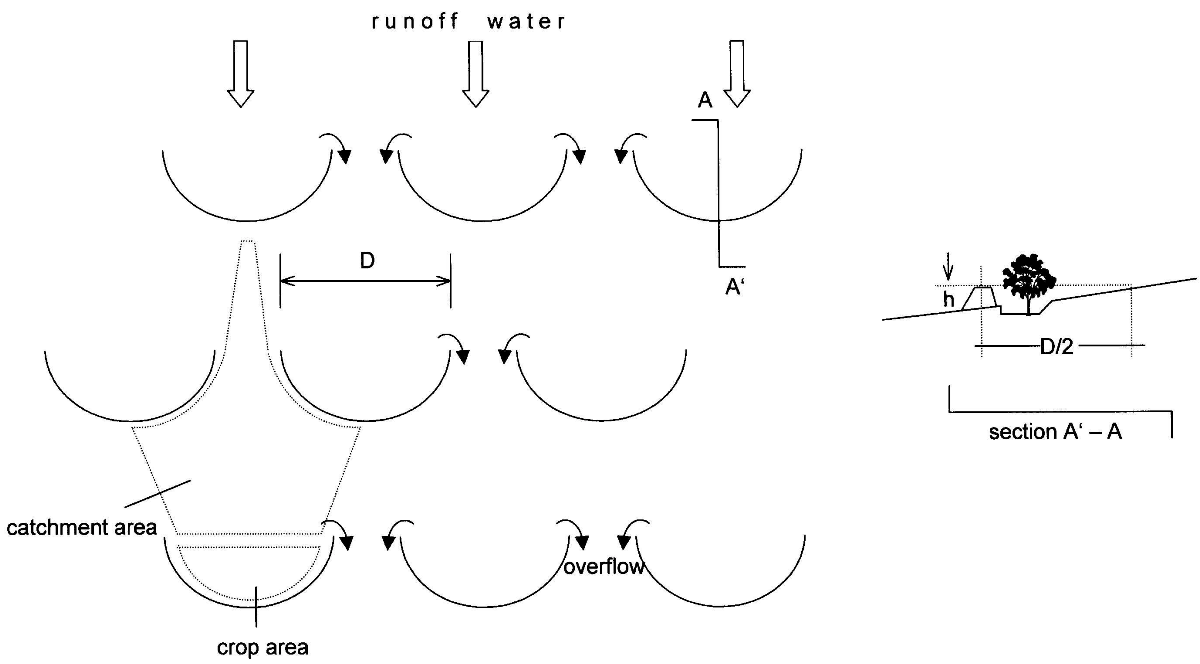

Fig. 3.1 Field layout of semi-circular bunds (redrawn after HAI 1998).

3.5.1 Crop water requirements

First, it is necessary to assess the amount of water that a fruit tree requires in order to grow successfully. Crop water requirements can be calculated from modeled or measured evapotranspiration rates. Evapotranspiration depends on climatic parameters, crop factors and management and other environmental conditions (such as soil parameters, undergrowth, planting density etc.). Several methods have been devised to estimate evapotranspiration rates based on environmental parameters (see ALLEN et al. (1998) for an overview). This study uses a simple equation, where crop evapotranspiration rates are derived from potential evapotranspiration[30] rates and transfer functions for the respective crops (ALLEN et al. 1998). The mean annual crop water requirement (CWR) is given as

$$CWR = \sum_{Jan\,1}^{Dec\,31} ET_c\,[\,mm/day\,]$$

where ET_c is the daily evapotranspiration of the crop and is approximated by

$$ET_c = ET_0 \cdot K_c\ .$$

ET_0 is the potential evapotranspiration (in mm/day) and K_c is a factor adjusting this value for the individual crop. Both parameters depend on the local conditions. For Kakuma, three different approaches allow an estimate for ET_0. First, (DROPPELMANN 1999) measured potential evapotranspiration in Kakuma and found an average value of 7.9 mm/day between April and November.

Second, the Blaney-Criddle method (ALLEN et al. 1998) uses the equation

$$ET_0 = p \cdot (\,0.46 \cdot T_{mean} + 8\,)$$

for obtaining a value for ET_0. T_{mean} is the average daily temperature and p is the mean daily percentage of annual daytime hours (depending on the latitude). For Kakuma, the Blaney-Criddle Method yields ET_0 = 5,8 mm/day.

[30] The potential evapotranspiration (also called standard crop evapotranspiration) is defined here as the sum of evaporation and transpiration of a "uniform grass surface, not short of water" (ALLEN et al., 1998).

Finally, ALLEN et al. (1998) give E_0 guidelines for different climatic zones, providing 6 – 8 mm/day for semi-arid conditions in tropical climates. Table 3.6 summarizes the ET_0 values obtained for Kakuma using the different approaches.

Table 3.6 Potential evapotranspiration (ET_0) in Kakuma, northern Kenya, using three different calculation approaches (ALLEN et al. 1998, climatic data for Kakuma: DROPPELMANN 1999)

Source	ET_0 [mm/day]
Penman method	7.9
Blaney-Criddle method	5.8
ET_0 standard value (arid conditions, tropical climate)	6.0 – 8.0

For further calculations, we assume a ET_0 value of 7 mm/day, using 5.8 mm/day and 8.0 mm/day in the sensitivity analysis.

In order to compute the crop water requirements, ET_0 must be multiplied with the crop coefficients K_c of mango, guava and papaya respectively. ALLEN et al. (1998), HAI (1998), and the Applied Research Institute Jerusalem (ARIJ, 1996) give indications of average K_c values for these species. Table 3.7 calculates average crop water requirements, as well as a range of values used for sensitivity analysis.

Table 3.7 Crop water requirements for mango, guava and papaya in Kakuma, northern Kenya (K_c values for mango and papaya in HAI (1998), for guava in ARIJ (1996), error ranges estimated); $CWR = E_0 \cdot K_c$; E_0 = 5.8 – 8 mm/day ($E_{0,mean}$ = 7 mm/day).

Species	K_c	Crop water requirement [mm / year]	
		Range	Mean
Mango	0,67 ± 0,1	1207 - 2248	1712
Guava	0,55 ± 0,1	953 - 1898	1405
Papaya	0,93 ± 0,1	1757 - 3008	2376

3.5.2 Root uptake area and total water requirement

The next step is to calculate the area from which the tree actually takes up the water. According to HAI (1998), the root uptake area[31] (RUA) for a mature tree can be approximated by its canopy area. Therefore, we estimate RUA to be equal to the spacing of trees in a conventional plantation, since those space requirements are designed to avoid both root and canopy competition among the trees.[32] Multiplying the crop water requirement with the root uptake area yields the total water requirement (table 3.8).

Despite the higher relative water requirements (in mm/year) of a papaya plantation, the total water requirement (in liters per year) of a single papaya tree is much less than that of a mango. The reason is that mango takes up the water from a much greater surface area than papaya. Therefore, planting mangoes in micro-catchments requires much larger bunds than planting papayas in the same system.

Table 3.8 Spacing and average root uptake area of mango, guava, and papaya in common rainfed plantations (data from MORTON 1987, VAN EA 1992, and WESSELER 1996, $n_{total} = 10$), total water requirements for Kakuma (CWR: mango 1712 mm, guava 1405 mm, papaya 2376 mm; compare table 3.7 for details).

Species	Spacing (range) [m x m]	Average root uptake area [m^2]	Total water requirements [liters per tree and year]
Mango	6×8 – 18×18	80	136,960
Guava	4×5 – 6×7	30	42,150
Papaya	2,5×2,5 – 3×3	7,56	17,963

[31] The term "root uptake area" in this work means the surface area from where the plant takes up most of its water.

[32] A young tree has a smaller root uptake area and therefore requires less water for optimal growth. However, the bunds have to be planned for the trees to receive sufficient water throughout their entire lifetime. Consequently, the bund size is determined by the water requirements of a mature tree, not those of a seedling.
If adult trees managed to reach the groundwater, their rainwater requirements can be significantly reduced. However, a study of Groundwater Survey Kenya (GSK Ltd., 1993) showed that in Kakuma the first aquifer runs at about 30m depth., this is not the case. Another factor leading to the perception of adult trees requiring less water is *drought tolerance*. A mature tree may be less vulnerable to even prolonged periods of drought, which makes them seem requiring less water. The irrigation systems are planned for the entire lifetime of the tree and must satisfy their long-term water requirements.

3.5.3 Design rainfall and runoff water

Having determined the water requirements for a single tree, we move on to calculate the runoff surface necessary to supply this water. The amount of water that has to be contributed by runoff is obtained by subtracting the rainfall amount from the crop water requirement.

$$Runoff\ \ water = CWR - DR$$

The "design rainfall" (DR) is an important decision to be made when setting up a runoff irrigation system. It represents the amount of rainfall for which the system is designed to operate. The runoff generated by the design rainfall should guarantee sufficient water supply of the trees even in years with below average rainfall. HAI (1998) recommends to choose the design rainfall as to ensure "suitable irrigation at least two out of three years" and gives 370mm for Kakuma. For fruit trees, the value should be higher than that, since one year of drought can jeopardize the entire achievement of the previous years. Fig. 3.2 shows the expected rainfall stochasticity for Lodwar[33] and Kakuma from data on stochastic distribution of annual rainfall in Turkana. The design rainfall determines the amount of runoff expected, and therefore the necessary runoff surface to meet the crop water requirements.

[33] Lodwar, the capital of the Turkana district, hosts the only meteorological station in the area from which long-term rainfall data is available. Lodwar is located about 120 kilometers away from Kakuma and although it is somewhat drier, the two places show similar rainfall patterns.

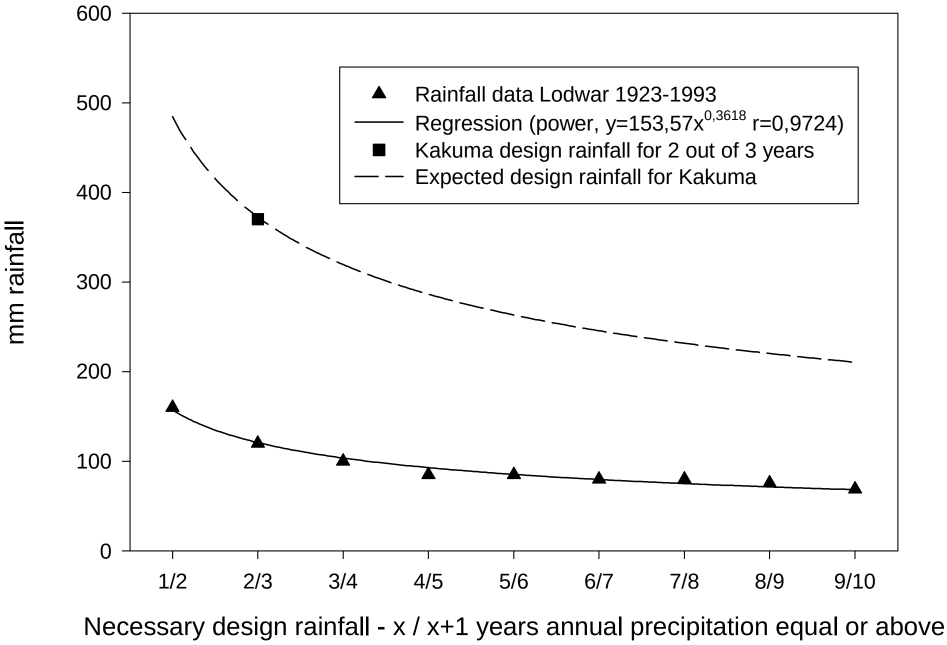

Fig. 3.2 Design rainfall for Kakuma and Lodwar, northern Kenya. The figures on the x-axis indicate the fraction of years in which the rainfall is equal or greater than the rainfall given by the graph. For example, in 5 out of 6 years, the expected rainfall in Kakuma is 262mm or more. Rainfall data for Lodwar (LITTLE & LESLIE 1999), n=69, exponential regression. Design rainfall for Kakuma, regression curve deducted from the Lodwar curve:

$$DR_{Kakuma}(\,x\,out\,of\ \ x+1\ years\,) = 153{,}57x^{0{,}3618}\cdot\frac{370mm}{120mm}$$

Therefore, the design rainfall for Kakuma is obtained by multiplying the regression value for Lodwar with the relative rainfall amounts of Kakuma versus Lodwar. This ratio is expressed by the 2 out of 3 years design rainfall, given by ERUKUDI (1991) for Kakuma and calculated from rainfall data (LITTLE & LESLIE 1999) for Lodwar.

3.5.4 Catchment to crop area ratio and bund diameter

The next step consists of calculating the "catchment to crop area ratio" (CCAR). The crop area itself receives the design rainfall and the difference between the crop water requirement and the design rainfall has to be contributed by the catchment area. Thus,

$$CCAR = \frac{CWR - DR}{DR \cdot c \cdot e}$$

where c is the runoff coefficient and e is the efficiency factor. This calculation is based on a simplified model[34] that assumes that over the course of a rainy season, a constant fraction *c* of the total rainfall is produced as surface runoff. As this runoff is kept in the crop area inside the bunds, again a certain fraction, *e*, is stored, taking into consideration losses that occur due to water evaporation and percolation. The variables *c* and *e* are determined by land surface, soil type and rainfall patterns. ERUKUDI (1991) researched runoff irrigation in Turkana and gives c = 0.5 and e = 0.4 for Kakuma.

With the catchment to crop area ratio, the total required area per tree (TRA) can be computed as

$$TRA = root\ uptake\ area \cdot (1 + CCAR).$$

Dividing the total available land area by TRA yields the number of trees to be planted in the irrigation system.

Furthermore, root uptake area and catchment to crop area ratio allow to compute the diameter (D) of the semi-circular bunds: HAI (1998) gives the equation

$$D = 0.898 \cdot Root\ uptake\ area^{1/2} \cdot (1 + CCAR)^{1/2}.$$

[34] A more sophisticated model is the so-called "SCS Curve Number Method" (HAI 1998) . It determines the amount of runoff generated by a single rainstorm (depending on the amount of rainfall), considers the distribution of rainstorm magnitudes throughout the season and adds up all the rainstorms that generate runoff (ORON et al. 1983). This method is more precise, but requires exact meteorological data. For Kakuma, such data were not available for a sufficient time span, therefore this study uses the simpler method described above.

The bund diameter, in turn, indicates how much working time is required for the construction of the entire system. Bunds with large diameter take disproportionally longer to construct than small bunds, since large bunds have to be built higher. For a regression analysis of the relationship between working time and bund size, see annex 2.

For our calculations, we assume a water harvesting structure that assures sufficient watering in 5 out of 6 years, corresponding to a design rainfall of 262mm. For the sensitivity analysis, we additionally calculate a lower risk scenario (9 out of 10 years) and a higher risk scenario (3 out of 4 years).

Table 3.9 summarizes the calculation benchmarks for structures built on a 3-hectare site. The number of species that can be planted on a given area varies considerably, reflecting the differing water requirements of the species.

Table 3.9 Risk tolerance, design rainfall and construction parameters (number of trees, bund diameter and construction time for mango, guava and papaya respectively) for a 3-hectare micro-catchment system in Kakuma, northern Kenya. Various data sources, see text.

Risk tolerance (sufficient water x out of y years)	Design rainfall [mm]	Trees per plantation (3 ha)	Bund diameter [m]	Construction time for entire plot [mandays]
3 out of 4 years	308	Mango: 16	Mango: 39.2	Mango: 166
		Guava: 53	Guava: 21.3	Guava: 215
		Papaya: 115	Papaya: 14.5	Papaya: 256
5 out of 6 years	262	Mango: 13	Mango: 43.0	Mango: 160
		Guava: 44	Guava: 23.5	Guava: 206
		Papaya: 96	Papaya: 15.9	Papaya: 245
9 out of 10 years	213	Mango: 10	Mango: 48.3	Mango: 152
		Guava: 35	Guava: 26.5	Guava: 195
		Papaya: 77	Papaya: 17.8	Papaya: 233

3.6 Macro-catchment scenario

In the second scenario, we assume that the fruit trees be planted into a macro-catchment runoff irrigation system, where water from an intermittent stream is guided into leveled basins. In contrast to the micro-catchment approach, these basins contain more than one tree. All trees planted in the system receive an equal amount of water. Under optimal conditions, the spacing between the individual trees is the same as in a rainfed plantation. The total amount of water available to the plants is then determined by the number of floods and the water level in the basins.

3.6.1 Pilot project for a macro-catchment runoff irrigation system in Kakuma

LEHMANN (1998) built a macro-catchment system in Kakuma in 1994, laying out four large basins on the contour, each 210×30m in size (fig. 3.3). The runoff water originates from a nearby mountain range and forms a seasonal stream which feeds the irrigation channel of the system. The irrigation structures were planted with fodder trees (*Acacia saligna* (Labill.) H.L. Wendl.), sorghum (*Sorghum bicolor* (L.) Moench) and cowpea (*Vigna unguiculata* (L.) Walp.) as well as fruit trees in the later stages of the project (LEHMANN, unpubl. data).

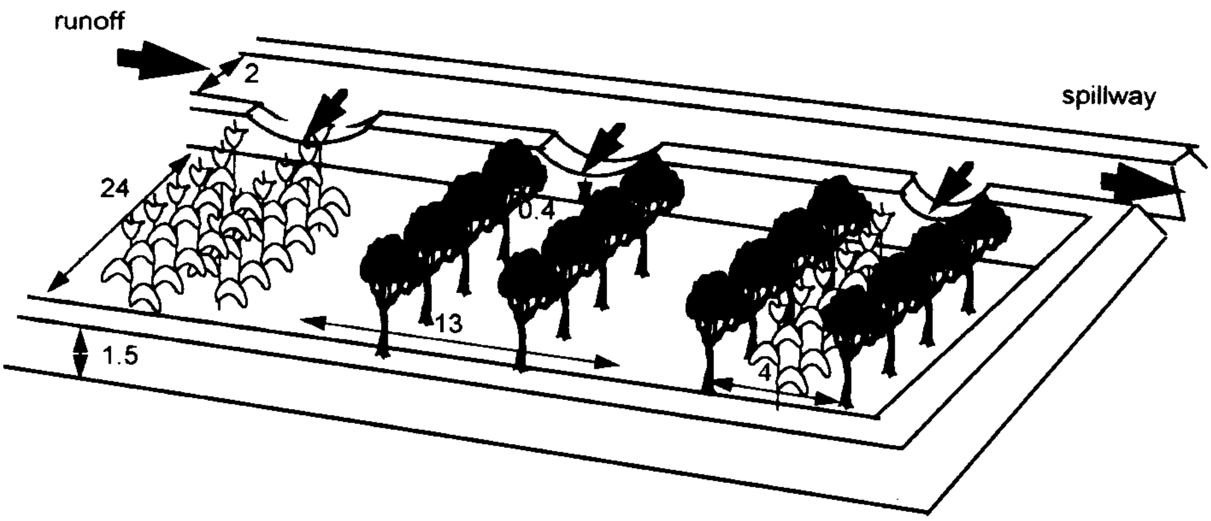

Fig 3.3 Macro-catchment runoff irrigation system built by (LEHMANN 1998) with *Acacia saligna* and *Sorghum bicolor*. The intermittent stream is connected to a system of irrigation channels that guide the runoff water into the individual basins.

The main difference between the two irrigation methods is that in the macro-catchment system, the irrigation water is harvested outside the actual planting surface. This allows a higher planting density. On the other side, the water supply is not a construction parameter (such as the bund size of micro-catchments), but depends on the catchment area of the intermittent stream.

Original construction costs of the system (LEHMANN, unpubl. data) were applied to the cost-benefit calculations for this scenario.[35] Table 3.10 details a list of the costs broken down into the various types of work.

Table 3.10 Costs of building a macro-catchment runoff irrigation system near Kakuma, northern Kenya. Values in KSh, construction in 1994, inflation accounted for.

Type of Work	Costs	
	[KSh]	[%]
Hire of excavator	81,136	18.5
Hire of tractor	11,738	2.7
Machinery maintenance and fuel	158,988	36.3
Expert salaries	97,849	22.3
Manual labor	67,293	15.4
Material costs	20,831	4.8
Total	437,835	100.0

We now move on to calculate the number of fruit trees for each species that can be planted into the four basins.

3.6.2 Water supply and planting density

Ideally, the planting density of trees in a macro-catchment system would be equal to that in a rainfed plantation (compare Table 3.8 in Chapter 3.5.2). A necessary prerequisite for this is that the water requirements of the trees (1405 - 2376 mm/year, compare Table 3.7 in Chapter 3.5.1) can be met by the floods occurring during the rainy seasons.

[35] Adjustments were made for manual labor, where the labor costs outlined in Chapter 4.3.2 were used. Furthermore, a total inflation rate of 67% in Kenya between 1994 and 2000 was included in the costs.

(DROPPELMANN 1999) gives the seasonal water use (WU) of the trees in the system as

$$WU_i = R_i + FI_i + \Delta SW_i$$

where R is the rainfall, FI the amount of water contributed by flood irrigation and ΔSW the change in soil water content. The parameter i denotes the time span. FI_i is the sum of all flooding events during the considered time period. For our calculations, we assume that

$$\Delta SW_i = 0$$

since the fruit trees cannot permanently drain water from the soil.
During the experiments conducted by (LEHMANN 1997), it was found that a single flood can fill the basins up to 500mm. A part of the water evaporates, the rest infiltrates into the soil. The number of floods and the amount of water supplied by the system varied considerably between the years. Table 3.11 provides an overview of the water supply between 1994 and 1999.
In general, the supplied irrigation water should be sufficient for mango and guava (annual water requirement 1405 and 1712mm respectively), yet it might lead to water stress for papaya (2376mm), at least in some years.

Table 3.11 Irrigation water supply into a macro-catchment runoff-irrigation system near Kakuma, northern Kenya; number of floods and mm/year, bracketed numbers are estimates; (LEHMANN 1997; DROPPELMANN 1999; LEHMANN unpubl. data).

Year	Total rainfall [mm]	Number of floods	Irrigation water [mm/year]
1994	[308mm]	4	[1290]
1995	374mm	4	1217
1996	330mm	7	1675
1997	[308mm]	11	[2250]
1999	[308mm]	8	[2210]
Average		6.8	1728

Although the water supply cannot be influenced by construction parameters, a lower planting density can improve water availability to a certain extent by increasing the total area for water uptake by the plants. This is mainly caused by two circumstances. First, an increased spacing allows the roots to advance further into the soil due to a reduction of intraspecific competition for soil water. Second, lateral water flow along a soil moisture gradient will increase the water supply to each individual plant. This water would have been taken up by the neighboring plant in more densely planted stands.

One possibility to make use of the space gained by decreasing planting density is to intercrop the fruit trees with annual plants such as sorghum or cowpea. This scenario, however, is beyond the scope of this study. For the standard calculations, we assume that mango and guava are planted at normal, papaya at reduced (50%) density. The other combinations of species and planting density are considered in the sensitivity analysis (Table 3.12).

Table 3.12 Planting density of a 3-hectare macro-catchment irrigation system in Kakuma, northern Kenya; 4 basins, basin size 210×30m

Species	Minimum space requirement per tree [m^2]	Relative planting density	Number of trees in entire system (25200m^2)
Mango	80	1	315
Guava	30	1	840
Papaya	7.56	0,5	1667

3.7 Traditional Turkana sorghum cultivation

To allow an economic judgment of runoff irrigation techniques, the capabilities of irrigation systems must be placed in the context of already existing approaches to agriculture. Introducing new agricultural techniques to the Turkana must, in economic analysis as much as in development concepts, start with Turkana agropastoralism. In this study, a cost-benefit analysis of traditional sorghum farming is conducted to enable comparison with the irrigation scenarios. This chapter briefly describes the traditional sorghum gardens of the Turkana from an economic point of view.

Small-scale sorghum gardening has been practiced in Turkana for many years, although not uniformly. A number of the Turkana tribes (such as the Ngilukumong) have economies based on both pastoralism and agriculture. In the traditional Turkana society, sorghum growing went along well with pastoral production: fast-growing sorghum varieties did not constrain mobility, and the custom of returning to the same wet season grazing area each year allowed renewed cultivation of suitable sites. Sorghum gardening is practiced in those areas where rainwater runoff concentrates naturally, mainly in depressions along the floodplains of intermittent rivers (ERUKUDI 1991). The expression "rainfed farming" is therefore misleading, because traditional sorghum gardens are a form of runoff irrigation not requiring any additional structures, such as earth bunds (PACEY & CULLIS 1986). The land for cultivation is owned communally, but usufruct rights to grow sorghum are given by the local chief. Field sizes range from less than one and several hectares per family.

Before or after the onset of the rains, the Turkana women till the soil with a "dschembe" (hoe), sprinkling sorghum seeds on the ground and incorporating them into the soil. The crop ripens within two to three months, after which the sorghum is harvested and stored. During the growth stages, the planted area is guarded day and night, with children scaring off birds that feed on the sorghum.

Essentially, the traditional sorghum cultivation of the Turkana has evolved as a risk-spreading mechanism, adapted to environmental uncertainties. By diversifying into agropastoralism, the Turkana have managed to broaden their resource base and reduce their dependence on livestock.

Yields (and therefore revenues) from opportunistic rainfed farming vary from year to year, depending to the climatic conditions. This is in contrast to the scenarios described above, where runoff irrigation is used as a means of mitigating environmental unpredictability.

For the purpose of cost-benefit calculations, this work uses an exemplary scenario of 15 years, where 9 years are "good" years with typical yields, 4 years are "bad" years with reduced yields and 2 year are droughts where sorghum growing is not possible at all.[36]

[36] According to LITTLE & LESLIE (1999), a partial drought is likely to occur every 3-5 years, whereas a complete failure of the rainy season can be expected in one out of 10 years.

Chapter 4

Results and Discussion

4.1 Introduction

After having described the input factors for the cost-benefit-calculations, this chapter presents the results of these calculations for both the micro-catchment (chapter 4.2) and the macro-catchment (chapter 4.3) scenario. In each of the scenarios, the results are presented and discussed according to a uniform scheme.

- First, the three decision criteria (net present value, internal rate of return and benefit-cost ratio) judge economic profitability of the project, with all input parameters set to their standard value as outlined in chapter 3.[37] The discussion focuses on the key aspects of economic performance and is supplemented by a breakeven analysis. This illustrates the flow of values over the entire project time and the point in time from which onwards the project becomes profitable.

- Second, the sensitivity analysis investigates the response of the decision criteria to changes of the input parameters. This is done for each parameter individually as well as for all parameters simultaneously. On the basis of these calculations, the overall economic feasibility of planting fruit trees in runoff irrigation systems is evaluated.

Finally, chapter 4.4 compares the results of an exemplary cost-benefit analysis of traditional sorghum cultivation against the irrigation concept.

[37] For simplicity, these parameter settings are further referred to as the "standard conditions" of a scenario.

4.2 Micro-catchment scenario

Planting fruit trees in micro-catchments represents an approach involving only a minimum amount of capital. Therefore, it is geared to ensuring a profit while minimizing (financial) risk.

4.2.1 Decision criteria and breakeven analysis

The micro-catchment scenario provides a profitable opportunity for planting fruit trees only for papaya, while mango and guava show a negative net value. Table 4.1 gives an overview of the findings using the criteria defined in Chapter 2.2.2.

Table 4.1 Decision criteria for a 3-hectare micro-catchment plantation of mango, guava, and papaya in Kakuma, northern Kenya. Time horizon 15 years, discount rate 30%, see annex 5 for details.

Species	Net present value at 30% discount rate [KSh]	Benefit-cost ratio at 30% discount rate	Internal rate of return [%]
Mango	-70,248	0.50	15%
Guava	-7,489	0.96	29%
Papaya	200,689	1.89	86%

The breakeven analysis (fig 4.1) shows that papaya has an early breakeven point of around two years. Even if no discount rate is applied, mango and guava require 8 and 5.5 years respectively to yield a profit.

The papaya scenario is not just favorable in terms of overall benefits, but papaya also realizes these benefits fast. Against the backdrop of pastoral societies and their methods of resource exploitation, short-term profitability is a decisive criterion for adoption of runoff irrigation techniques.

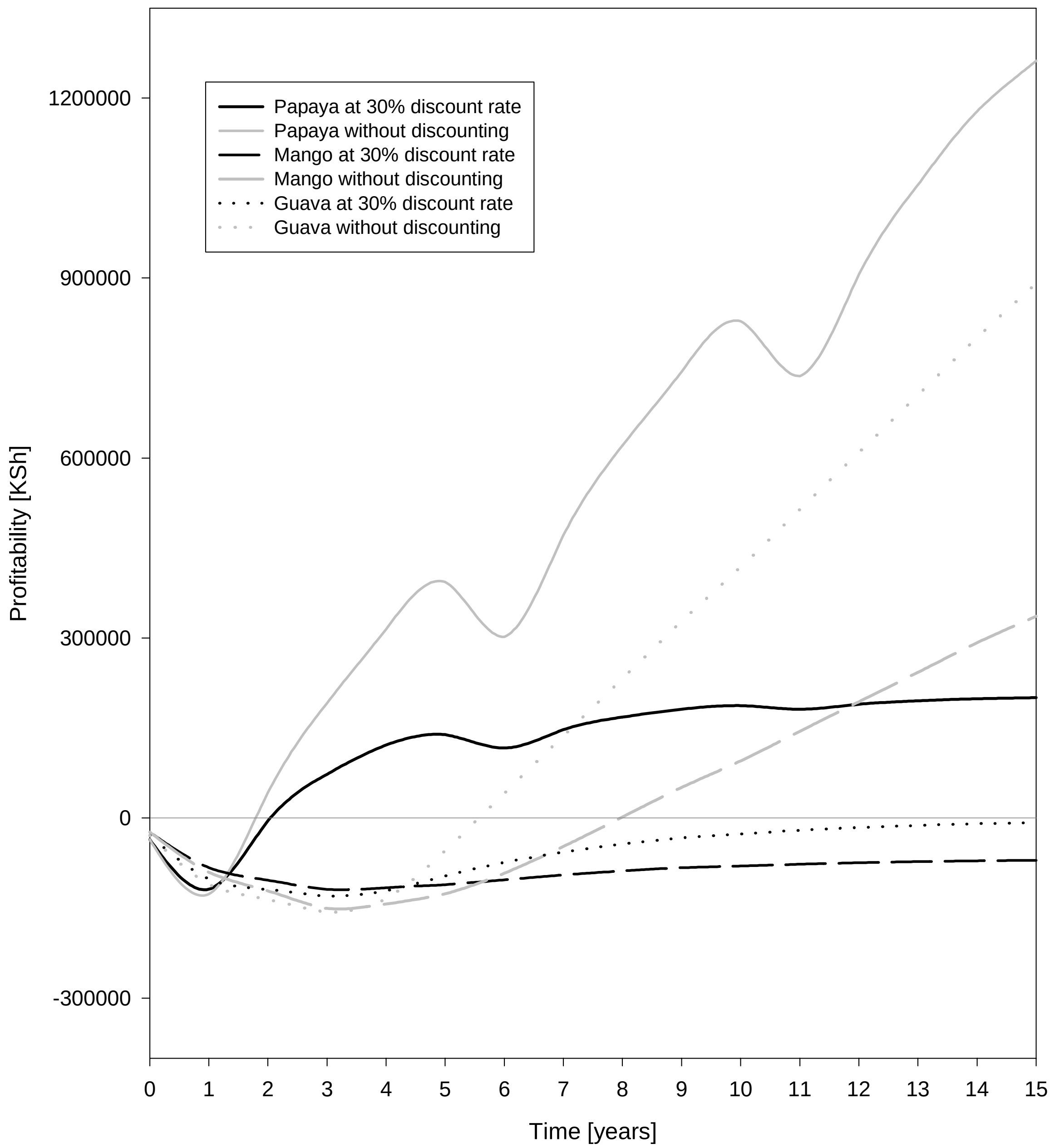

Fig. 4.1 Breakeven analysis for a 3-hectare micro-catchment plantation of mango, guava, and papaya in Kakuma, northern Kenya. Time [years] against profitability [KSh]; spline curves, with and without discounting of all costs and benefits, discount rate 30% p.a.. The papaya plantation is replanted after 5 years.

4.2.2 Discussion of the results

From an economic point of view, papaya has clear advantages over mango and guava. Essentially, two aspects explain the superior performance of papaya:

1. Papaya yields fruit rapidly (a maximum yield already in the second year), which becomes decisive if high interest rates are applied. For example, a maximum yield from a mango tree in year 7 earns 5380 KSh. Applying a discount rate of 30%, this amount is reduced to only 977 KSh present day terms. In contrast, the revenue from a papaya harvest of 2577 KSh in year 2 has a present value of 1739 KSh. Although a mango tree generates almost twice the yield value of a papaya (over a time horizon of 15 years), at a discount rate of 30%, the revenues generated by both species are roughly equal.

2. The total water requirements of papaya are much lower than those of the other species (see chapter 3.5.2). On a plot of 3 hectares, 96 papayas can be planted in micro-catchments, whereas on the same surface, the water harvested can supply only 13 mangoes.

After having looked at the benefits, the next question concerns the cost side of the calculations. In the micro-catchment scenario, nearly all costs occur in the form of manual labor. Table 4.2 provides an example of the working time spent for the various tasks in the runoff irrigation system (3-hectare plantation papaya, 96 trees, standard scenario):

It can be seen that maintenance plays a key role in the labor necessary for the irrigation system. In the first year, maintenance duties (including initial watering) are 3.46 times the building costs of the system. Thereafter, annual labor requirements amount to 80% to 107% of the original construction costs.

Many attempts to introduce runoff farming silently assumed that water harvesting structures do not require much maintenance once they are set up. In contrast to that, table 4.2 shows that the construction itself does not comprise the bulk of the costs for working time. Even when the discount rate is taken into account,[38] maintenance remains the major cost driver of the project.

[38] In that case, construction costs gain of relative importance, since by definition they are accrued at the beginning of the project and are not discounted.

Table 4.2 Working time required for construction and maintenance of a 3-hectare papaya plantation in Kakuma, northern Kenya. First planting cycle (5 years), standard conditions (see text); source: author's own data.

Type of task		Working time required
Site selection and fencing (3 hectares)		18 mandays[39]
Construction of 96 bunds (15.9 m diameter) and planting		459 mandays[40]
Initial watering (first 2 months)		555 mandays
Guarding and maintenance	year 1	1096 mandays
	year 2 onwards	218 mandays per year
Selling the produce	year 2 onwards	164-294 mandays per year

In Chapter 3.3.8, we already discussed the problem of guarding the plots from livestock, possibly even from human interference. In fact, time spent for other maintenance activities (such as bund maintenance, fertilization and pest control) is lower than the working time necessary for guarding the sites.

In summary, the combination of high maintenance costs and late harvests are the main reasons for the poor performance of mango and guava in the micro-catchment scenario.

The high maintenance input necessary may also be one reason why the Turkana have in the past not supported the water harvesting systems built for them. After withdrawal of the projects providing the funds for setting up the structures, the Turkana still had to "pay" the significant labor costs for upkeep. On the other hand, high maintenance costs favor irrigation scenarios with a higher initial input. If maintenance costs are significant, then the higher construction expenditures may in fact not be an argument against structures which generate higher benefits. This question will be considered later in the macro-catchment scenario (Chapter 4.3).

[39] Actual construction time is only 10 mandays. The figure takes into account that labor costs for fencing and digging microcatchments are twice as much as for other tasks, since physically demanding work is paid at a higher rate (compare chapter 3.3.2)

[40] Actual construction time is only 238 mandays. See note 33 above.

We now turn to the sensitivity analysis, considering uncertainty parameters of the calculations.

4.2.3 Single-factor sensitivity analysis

The sensitivity analysis investigates how the variability of the input parameters influences the decision criteria of the micro-catchment scenario.
Table 4.3 shows the result of the single-factor sensitivity analysis[41], indicating the cost-benefit ratio for every sub-scenario generated by the respective parameter variations. The upper part of the table considers factors depending on management choices regarding the irrigation system (for example construction parameters). The lower part deals with uncertainty factors that can not (or at least not directly) be influenced by the farmer.
It can be seen that mango is not profitable in any one of the sub-scenarios. Guava is profitable in some cases, depending on which input factor is subject to change. Papaya retains its profitability in most sub-scenarios.
More important than examining the profitability of the species, the single-factor analysis serves to rate the input parameters in terms of their importance to the overall assessment. In the micro-catchment scenario, two input factors play a decisive role in the economy of the system: labor expenses and yield data. The discount rate is crucial for guava and mango, less for papaya which bears fruit early. The sub-scenarios concerning initial watering and guarding the trees are also important.
The variability of labor costs and yield expectations make it difficult to predict the project outcome. Labor costs, for example, are increased both by higher wages and by an underestimation of the working time. The same is true for the income generated by selling the harvest with regard to the number of fruits harvested and their selling prices.

[41] The term "single-factor sensitivity analysis" is used here to indicate the variations of only one parameter. Accordingly, "multi-factor sensitivity analysis" describes the simultaneous variation of all input parameters.

Table 4.3 Single-factor sensitivity analysis for a 3-hectare micro-catchment plantation of mango, guava, and papaya in Kakuma, northern Kenya. Lines printed in bold type indicate standard conditions, numbers in the table are cost-benefit ratio. Source: author's own data.

Input parameter	*Value*	*Cost-benefit ratio*		
		Mango	*Guava*	*Papaya*
a) Management options				
Target group	**Turkana**	**0.50**	**0.96**	**1.89**
	Refugees	0.33	0.66	1.39
Initial watering	no initial watering	0.51	1.04	2.29
	initial watering 2 months	**0.50**	**0.96**	**1.89**
	initial watering 6 months	0.45	0.74	1.27
Seedling production	**private nursery**	**0.50**	**0.96**	**1.89**
	commercial nursery	0.49	0.94	1.85
Number of seedlings planted per catchment	1	0.51	1.02	2.12
	2	**0.50**	**0.96**	**1.89**
	3	0.48	0.90	1.70
Tree management efforts	half	0.50	0.99	2.00
	normal	**0.50**	**0.96**	**1.89**
	double	0.48	0.90	1.70
Guarding the plots	**only seedlings**	**0.50**	**0.96**	**1.89**
	fruiting trees	0.30	0.64	1.20
Risk tolerance (design rainfall)	308mm	0.58	1.10	2.06
	262mm	**0.50**	**0.96**	**1.89**
	213mm	0.40	0.80	1.68
b) Uncertainty factors				
Crop water requirement	low	0.83	1.33	2.21
	normal	**0.50**	**0.96**	**1.89**
	high	0.44	0.74	1.65
Costs of labor / working time	half	0.93	1.82	3.41
	normal	**0.50**	**0.96**	**1.89**
	double	0.26	0.49	0.99
Survival rate	95%	0.58	1.10	2.14
	80%	**0.50**	**0.96**	**1.89**
	60%	0.38	0.74	1.51
Yield data / selling prices	double	0.95	1.77	3.27
	normal	**0.50**	**0.96**	**1.89**
	half	0.25	0.50	1.02
Discount rate	20%	0.79	1.40	2.19
	30%	**0.50**	**0.96**	**1.89**
	50%	0.23	0.49	1.46
Time horizon	**15 years**	**0.50**	**0.96**	**1.89**
	10 years	0.41	0.84	1.82

Legend: green = profitable (CBR>1.2); yellow = marginally profitable (1≤CBR≤1.2); red = not profitable (CBR<1)

a) Labor costs

It should be noted that this study used the strict market price of labor (compare chapter 3.3.2) not a “fair” salary, as it is usually paid by development agencies. For example, a papaya plantation looses its profitability if the labor costs exceed 110 KSh, a per diem salary of around 1.5 US$. Practically, this means that a non-profit project could pay this amount to its workers without running losses as a whole. In comparison, the average salary paid by aid agencies to Turkana is 154 KSh. Therefore, it has to be concluded that low labor costs represent an important prerequisite for the economic feasibility of micro-catchment systems. Higher labor costs could only be tolerated if protection of the sites were not necessary. These findings highlight the problematic nature of setting up agricultural structures as isolated islands in pastoral environments.

b) Yield data

The significance of the yield data points to the question whether fruit trees are able to produce normal yields under runoff irrigation in climatic conditions as in Kakuma (compare chapter 3.3.9). If yields fell below 49% of the standard values anticipated in this study, papaya would lose its profitability. Equally, if yields were more than 211%, even a mango plantation would become a profitable investment. Conducting ecophysiological field studies could help to clarify this point.

If refugees were allowed to build and use water harvesting structures around the camp, their labor costs would be significantly higher than those of the Turkana. At the same time, the protection problem would remain unresolved. Therefore, the Turkana seem the more logical target group for this irrigation system.

Seedling costs and the number of seedlings planted are less important. Here, it is recommended to establish more seedlings in the beginning (when they do not compete for water resources yet) in order to guarantee the desired planting density despite a certain mortality of the young trees.

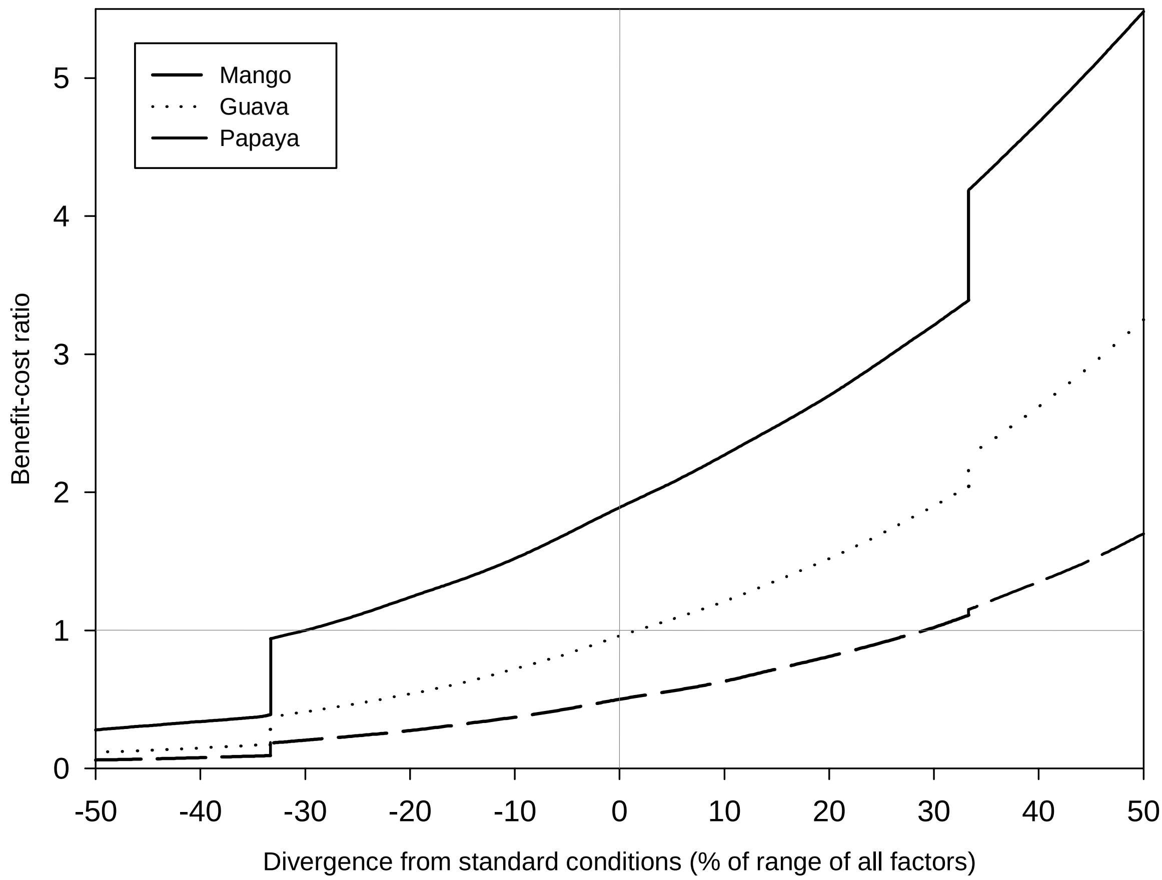

Fig. 4.2 Multi-factor sensitivity analysis for a 3-hectare micro-catchment plantation of mango, guava, and papaya in Kakuma, northern Kenya. Divergence of sensitivity factors from the standard conditions (% of total sensitivity range) against benefit-cost ratio; parameters that have no continuous value are "switched" at +33% and –33% respectively. Source: author's own data; compare table 4.3 for a list of parameters considered.

4.2.4 Multi-factor sensitivity analysis

As detailed in chapter 2, multi-factor sensitivity analysis examines the influence of a simultaneous variation of the input variables within the boundaries of their uncertainty range. Fig. 4.2 plots the benefit-cost ratio for the three species against the relative deviation of all input parameters[42] from their standard value. Papaya is profitable between +50.0% and –30.2% deviation, mango only above +29.0% deviation. Guava becomes profitable above +1.9% deviation.

[42] The target group parameter was always "Turkana".

Of the three species, only papaya is likely to yield a sustained profit despite the uncertainties involved. If more detailed information becomes known, for example on yield data or on labor costs, fig. 4.2 can be redrawn incorporating the knowledge gained.

In summary, **planting of fruit trees in micro-catchments should be considered for papaya only**. Labor costs are a significant constraint, clearly pointing to problems of the particular situation in Kakuma with over-abundance of livestock and the problems of integrating agriculture into a pastoral environment. Yield data is a major source of uncertainty where further research is needed.

4.3 Macro-catchment scenario

The macro-catchment scenario represents a more capital-intensive approach to runoff irrigation. Setting up an extensive structure with machinery implies a significant initial investment, aiming to maximize harvest revenues.

4.3.1 Decision criteria and breakeven analysis

Table 4.4 outlines the decision criteria for the macro-catchment approach. In contrast to the previous scenario, all three species are profitable. By economic measure, the macro-catchment system is a promising alternative to micro-catchments. Papaya again generates the highest value of the three species, yielding almost 24 times the NPV of the respective micro-catchment scenario.

Table 4.4 Decision criteria for a 3-hectare macro-catchment plantation of mango, guava, and papaya in Kakuma, northern Kenya. Time horizon 15 years, discount rate 30%, see annex 5 for details. Source: author's own data

Species	Net present value at 30% discount rate [KSh]	Benefit-cost ratio at 30% discount rate	Internal rate of return [%]
Mango	662,544	1.66	42%
Guava	1,624,141	2.07	52%
Papaya	4,813,465	2.86	138%

The result of the breakeven analysis (fig. 4.3) is similar to the micro-catchment scenario. Papaya has a breakeven point of less than two years, while guava and mango require a longer time (5.5 years and 7 years respectively) to reach profitability. Even without discounting, these two species require between 4 and 5 years until the benefits offset the costs.

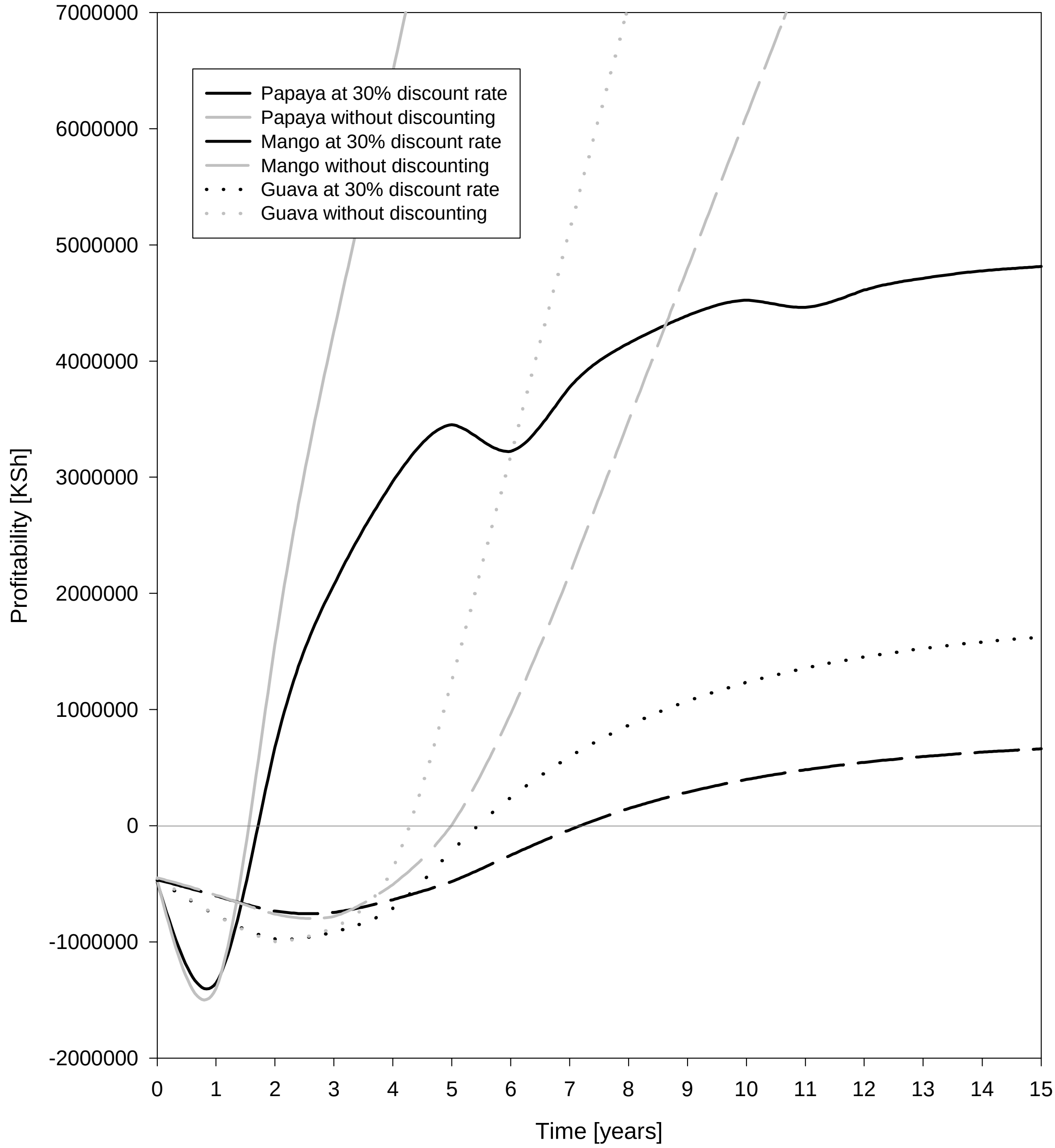

Fig. 4.3 Breakeven analysis for a 3-hectare macro-catchment plantation of mango, guava, and papaya in Kakuma, northern Kenya. Time [years] against profitability [KSh]; spline curves, with and without discounting of all costs and benefits, discount rate 30% p.a.. The papaya plantation is replanted after 5 years.

4.3.2 Discussion of the results

Comparing the two scenarios, the macro-catchment system is favorable both in absolute (net present value) and relative (benefit-cost ratio and internal rate of return) denominations of profitability. The main reason for this is the far greater number of trees that can be planted into the macro-catchment system. The harvest benefits generated by the fruiting trees overcompensate the initial investment necessary to build the structures.

For a three-hectare site, total construction costs of the macro-catchment system are more than 10 times higher than those for micro-catchments. However, on a per-tree basis, costs of the large-scale system are actually less (table 4.5).

Therefore, the disadvantage of the macro-catchment approach is not a lack of economic efficiency, but the high initial investment necessary. Depending on the species, between 780,000 and 1,400,000 KSh have to be advanced before the benefits start to materialize. In the micro-catchment scenario, this figure ranges between 127,000 and 157,000 KSh only. A high initial investment also implies a significant risk. The costs outlined above correspond to the maximum economic loss in case of a devastating multi-year drought in the beginning stages of the project.

Mango, guava and papaya differ in their performance in the macro-catchment scenario. Papaya requires the largest initial investment and yields the highest profit. Mango and guava are less profitable and realize their gains only after several years, but require less initial capital.

Table 4.5 Comparison of construction costs per tree in Kakuma, northern Kenya; micro-catchment and macro-catchment irrigation systems; source: author's own data.

Species	Per-tree construction cost of a 3 ha micro-catchment system [KSh]	Per-tree construction cost of a 3 ha macro-catchment system [KSh]
Mango	2531	1392
Guava	863	522
Papaya	441	263

4.3.3 Single-factor sensitivity analysis

As in the micro-catchment scenario, a single-factor sensitivity analysis (table 4.6) rates the relative importance of the individual input parameters. In the macro-catchment scenario, profitability is retained in most cases. Mango is not profitable when a discount rate of 50% is applied.

In the macro-catchment scenario, high costs accrued at t=0 stand opposite to considerable benefits during later stages of the project. Consequently, the discount rate becomes a key factor for the overall assessment of the system. Again, papaya responds less than the other two species to changes in this input parameter. The internal rates of return (138% for papaya, 42% and 52% for mango and guava respectively) emphasize this finding.

As a central point to the benefits delivered by the project, the yield data retains its significance for economic viability. In this scenario however, all three species would still be profitable despite yield revenues dropping as low as 50% of their standard values.

The expenses for guarding the plots are less important in a large-scale system. Guarding the site constitutes a fixed cost, irrespective of the number of trees planted within the area that has to be taken care of by a watchman. Even 24-hour care throughout the entire project cycle would not have a significant impact on profitability. In fact, if this turned out to be necessary, a macro-catchment approach may well be the only feasible option of planting fruit trees in Kakuma.

As construction costs of the irrigation system amount to 31-56% of the initial investment, a variation in these costs has a visible impact on the final result. In contrast, costs for manual labor are still important, but do not quite have the same effect here as in the micro-catchment scenario. First of all, manual labor contributes only to a small extent (15.4%) to the construction costs of the system, and second, the fixed costs characteristics of manual labor mentioned above also play a role.

Table 4.6 Single-factor sensitivity analysis for a 3-hectare macro-catchment plantation of mango, guava, and papaya in Kakuma, northern Kenya. Lines printed in bold type indicate standard conditions, numbers in the table are cost-benefit ratio. Source: author's own data.

Input parameter	*Value*	*Cost-benefit ratio (CBR)*		
		Mango	*Guava*	*Papaya*
a) Management options				
Target group	**Turkana**	**1.66**	**2.07**	**2.86**
	Refugees	1.38	1.69	2.31
Initial watering	no initial watering	1.84	2.49	3.87
	initial watering 2 months	**1.66**	**2.07**	**2.86**
	initial watering 6 months	1.22	1.27	1.64
Seedling production	**private nursery**	**1.66**	**2.07**	**2.86**
	commercial nursery	1.65	2.05	2.83
Seedling planting density	single	1.84	2.48	3.49
	double	**1.66**	**2.07**	**2.86**
	triple	1.52	1.78	2.42
Mature tree planting density	**normal**	**1.66**	**2.07**	3.23
	reduced	1.03	1.48	**2.86**
Tree management efforts	half	1.79	2.35	3.26
	normal	**1.66**	**2.07**	**2.86**
	double	1.47	1.68	2.29
Guarding the plots	**only seedlings**	**1.66**	**2.07**	**2.86**
	fruiting trees	1.62	2.03	2.79
b) Uncertainty factors				
Macro-catchment construction cost	half	2.16	2.44	3.13
	normal	**1.66**	**2.07**	**2.86**
	double	1.14	1.59	2.43
Costs of labor / working time	half	2.05	2.61	3.65
	normal	**1.66**	**2.07**	**2.86**
	double	1.21	1.47	1.99
Survival rate	95%	1.91	2.35	3.19
	80%	**1.66**	**2.07**	**2.86**
	60%	1.31	1.66	2.33
Yield data / selling prices	double	2.73	3.38	4.55
	normal	**1.66**	**2.07**	**2.86**
	half	1.04	1.27	1.69
Discount rate	20%	2.59	2.99	3.28
	30%	**1.66**	**2.07**	**2.86**
	50%	0.75	1.06	2.22
Time horizon	**15 years**	**1.66**	**2.07**	**2.86**
	10 years	1.41	1.84	2.78

Legend: green = profitable (CBR>1.2); yellow = marginally profitable (1≤CBR≤1.2); red = not profitable (CBR<1)

4.3.4 Multi-factor sensitivity analysis

Fig. 4.4 plots the simultaneous variation of all input parameters against the cost-benefit ratio of the project. It can be seen that all three species are fairly resilient against changes in the parameters. Mango is profitable up to –25%, guava and papaya up to –33% deviation from the base values. However, non-continuous factors are more important here, mainly in case of a negative deviation. The importance of these factors is mostly attributed to the combination of planting more seedlings (3 instead of 2) and watering these seedlings over an extended period of time (the entire first dry season as opposed to two months in the beginning). For example, papaya would remain profitable up to –64% deviation if these two factors were left unchanged. Further experimentation could bring clarification, as to whether this is a realistic assumption.

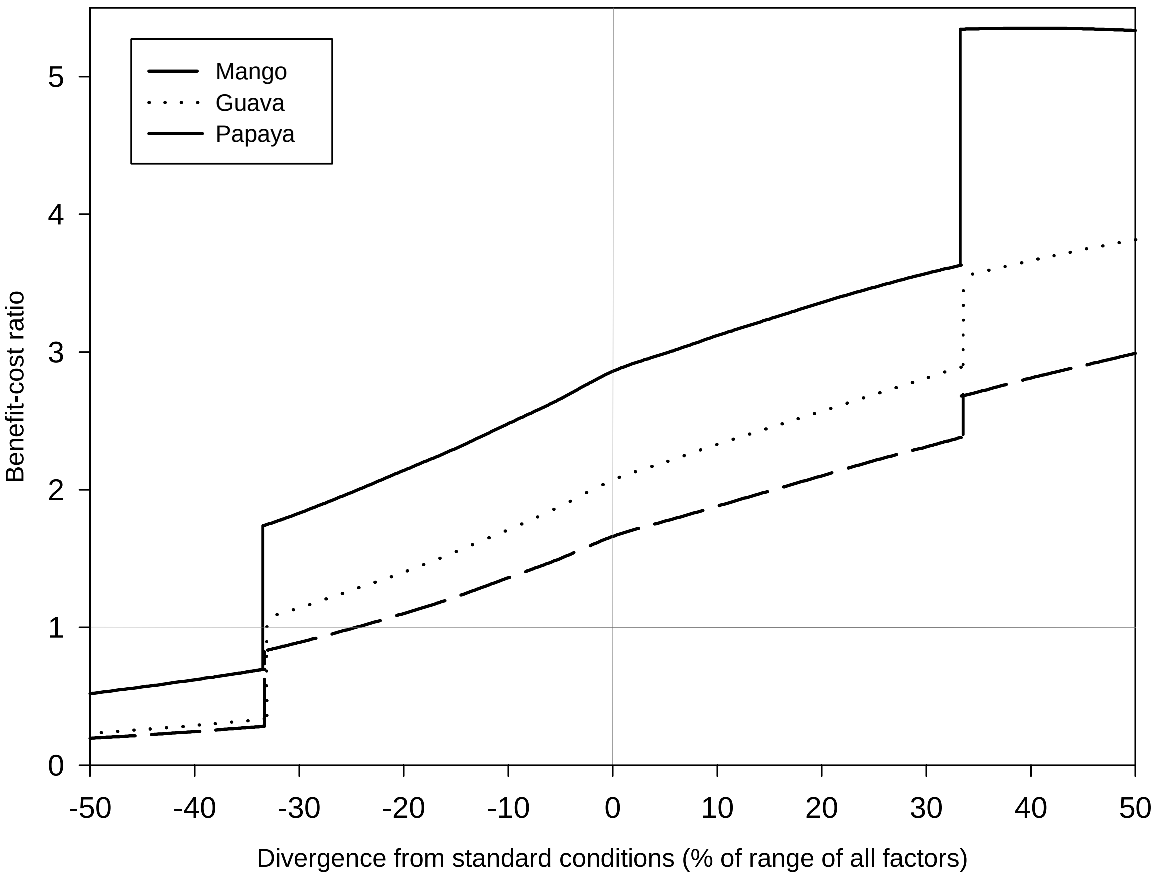

Fig. 4.4 Multi-factor sensitivity analysis for a 3-hectare macro-catchment plantation of mango, guava, and papaya in Kakuma, northern Kenya. Divergence of sensitivity factors from standard conditions (% of total sensitivity range) against benefit-cost ratio; parameters that have no continuous value are "switched" at +33% and –33% respectively. Source: author's own data; compare table 4.6 for a list of parameters considered.

In conclusion, **the macro-catchment scenario is profitable for all three species and is likely to yield a profit despite uncertainties involved in the input parameters**. As in the micro-catchment approach, papaya is the best species to be planted.

However, it should be noted that a number of economic preconditions have to be in place in order to make planting fruit trees in this particular system feasible. Notwithstanding general constraints, a macro-catchment approach has two important economic limitations:

- Building large structures requires machinery. Therefore, a significant amount of financial capital is required. Construction costs totaling 438,000 KSh consist mainly (84.6%) of payments for machinery and qualified personnel. Sufficient funds would have to be provided by formal credit mechanisms.
- The turnover generated by a large irrigation system clearly surpasses the level of a Turkana family or awi (village). A high level of social organization must ensure that a sufficient workforce is available, that the fruit is sold on the market, and that the income generated is distributed. People working in the system must either be paid in cash or otherwise taken care of in order to meet their daily needs.

Currently, both conditions do not apply to the Turkana living around Kakuma. The latter of the two constraints may be overcome in the long run if acceptance of water harvesting techniques grows among the Turkana. However, credit facilities providing loans of several hundred thousand Shillings to poor pastoralists is clearly not a realistic assumption. Even if commercial banks could be convinced of the effectiveness of runoff irrigation, it seems unlikely that a loan would be handed out without any form of security. Microcredit programs, on the other side, issue only small loans[43], not capable of funding a project of this size.

A possible compromise would be to build smaller basins that could be constructed with manual labor, or to extend structures gradually, perhaps reinvesting revenues generated in earlier project stages. Both approaches warrant further research.

[43] For example, a loan of the IRC microcredit program in Kakuma encompasses a maximum of 8000 KSh.

4.4 Traditional Turkana sorghum cultivation

Traditional sorghum gardening yields a relatively small profit. Table 4.7 presents the decision criteria for an exemplary sorghum farm.

Table 4.7 Decision criteria for a 3 hectare traditional sorghum garden in Kakuma, northern Kenya. Time horizon 15 years, discount rate 30%, see annex 5 for details; source: author's own data

Species	Net present value at 30% discount rate [KSh]	Benefit-cost ratio at 30% discount rate	Internal rate of return [%]
Sorghum	46,950	1.33	10,089

Economically, traditional Turkana agriculture is characterized by risk evasion and a short time span between costs and benefits.

- Costs for establishment of the gardens are minimal. If planting is withheld until after the first rainstorm, a drought will not lead to a waste of resources. In any case, low expenses in terms of labor and capital minimize potential losses.
- Once the sorghum has germinated, it can be harvested 60-90 days later (BROWNE & DE GANS 1981). The rapid realization of the benefits is reflected in a (theoretical) internal rate of return of over 10,000 %.

Additionally, the low input necessary for establishing the farm in combination with the early harvests is efficiently dealing with labor shortages on a household level.
Figure 4.5 corresponds to the breakeven analyses conducted for the runoff systems (figs. 4.1 and 4.3) and depicts monetary flows of an exemplary Turkana garden. A profit from a good year (such as year 1) is partially reinvested in hope for another year with sufficient rainfall. After a bad year (year 2), profitability declines but another good year (year 3) compensates for that. In drought years (year 5), no loss is incurred if the farmer waits for the rains before sorghum is sown. Unlike a perennial cultivation, opportunistic rainfed agriculture establishes a "level playing field" after each season.

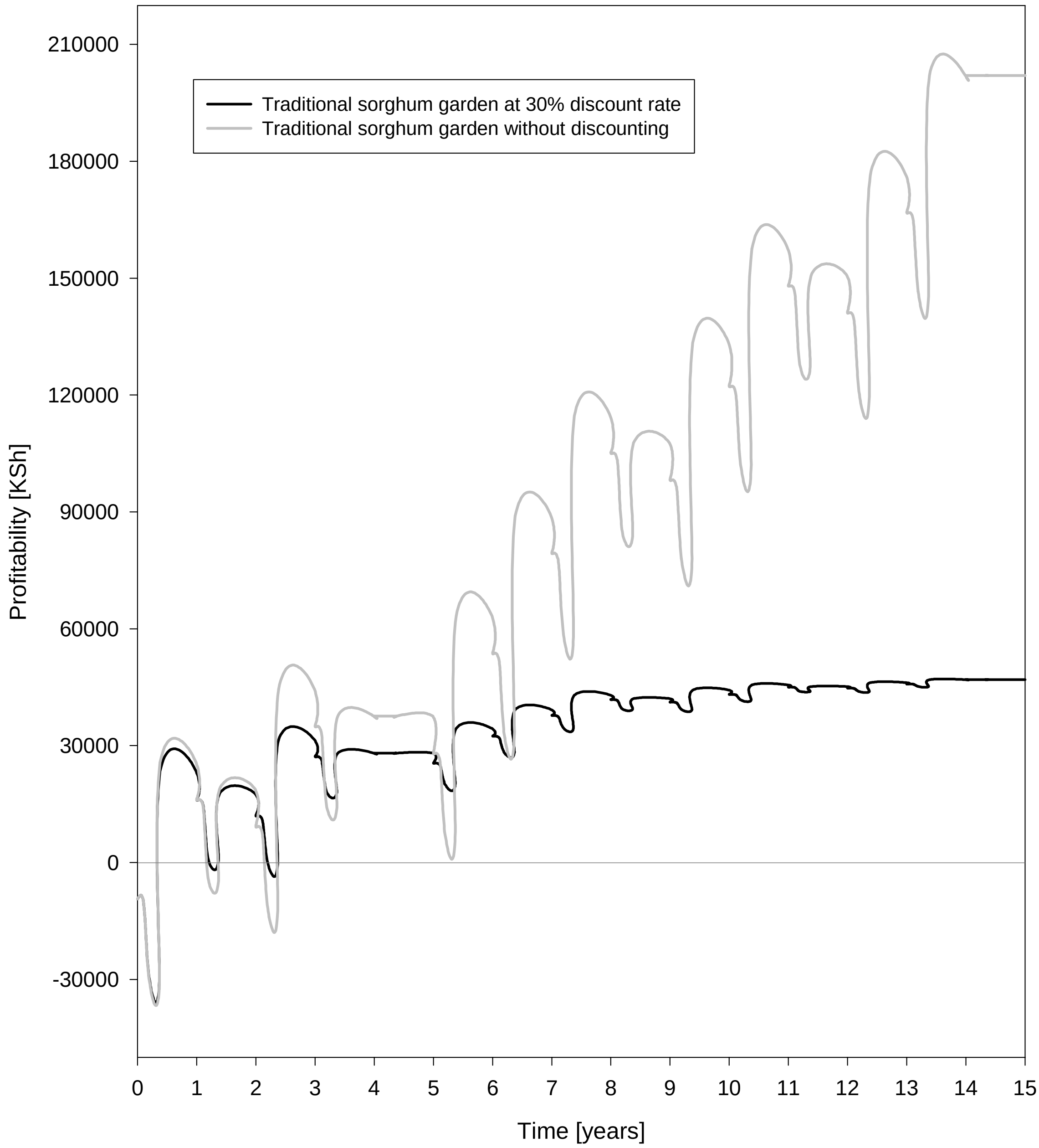

Fig. 4.5 Exemplary breakeven analysis for a 3-hectare traditional sorghum garden in Kakuma, northern Kenya. Time [years] against Profitability [KSh]; spline curves, with and without discounting of all costs and benefits, discount rate 30% p.a.. Partial droughts assumed in years 2, 4, 9 and 12; total droughts in years 5 and 15 (compare chapter 3.7). Source: author's own data.

The development of opportunistic rainfed agriculture allowed the Turkana to adapt to environmental unpredictability. Traditional sorghum gardens involve only minimal economic risk, offer high return rates and retain the flexibility necessary to fit into a pastoral way of life. The main disadvantage is that this approach cannot ensure food security in the long run.

Chapter 5

Conclusions

5.1 Cost-benefit analysis

Cost-benefit analysis has shown to be a useful tool in simulating the decision making process with regard to adopting water harvesting techniques. The approach is capable of capturing the local situation in terms of physical environment, commodity and factor markets, individual preference structure and risk tolerance. The three decision criteria chosen (net present value, benefit-cost-ratio and internal rate of return) are suitable to cover both absolute and relative profitability.

Complementing the decision criteria with a sensitivity analysis has proven useful in three respects. First, sensitivity analysis allows to project the relative importance of individual input parameters. Second, it evaluates how uncertainties connected to these parameters influence the final result. Finally, a multi-factor sensitivity analysis can validate the significance of the recommendations put forth by the decision criteria.

The study has shown the interdependence of ecological and economic factors in analyzing profitability. An interdisciplinary approach can provide a comprehensive capture of the key factors determining the potential of new land use techniques.

5.2 Profitability of runoff irrigation

Using runoff irrigation systems to plant fruit trees can potentially be a profitable enterprise in Kakuma. Some of the uncertainty factors could be reduced by conducting further research, especially on crop water requirements and fruit production under local climatic conditions.

Comparing the three species, papaya has significant advantages over both mango and guava. Lower total water consumption and early fruit production make papaya preferable in both scenarios investigated. In the micro-catchment scenario, the other species do not yield a profit.

The macro-catchment approach performs better than the micro-catchment approach with regard to all three decision criteria. If sufficient capital is available, building a macro-catchment system is preferable.

5.3 Fruit trees versus annual crops

In the past, water harvesting systems in Turkana have either focused on reforestation or on production of annual crops. Planting fruit trees instead of crops into irrigation systems involves two important economic implications.

Importance of the discount rate.

In this study a discount rate of 30% was applied, owing to the absence of formal credit mechanisms and to a risk premium to account for environmental and social uncertainty. High discount rates favor scenarios which generate benefits within a short time. This was shown in the dominance of papaya over mango and guava in this study. In this regard, an agroforestry approach that combines fruit trees with annual crops would have a potential to increase profitability even further.

Risk

Any project that generates revenues over the course of several years depends the factors responsible for the benefits to materialize. In Kakuma, a runoff irrigation system requires rainfall, irrespective of the technique applied to make use of it. For example, between July 1999 and July 2000, Kakuma witnessed not a single rainstorm event that produced significant surface runoff. According to the local population, such an event occurs in Turkana roughly every 10 years (EKENO, pers. comm.). The question whether a fruit tree plantation under runoff irrigation would have survived a drought like this cannot be answered by this study. Using runoff water to irrigate fruit trees provides an excellent opportunity for income generation, but a certain amount of risk cannot be ruled out. The amount of capital set at risk is substantially higher in the macro-catchment scenario than in the micro-catchment approach.

Trials to build a smaller macro-catchment system that can be constructed with manual labor have begun in Kakuma. If such a system is capable of generating sufficient water, it could be a promising alternative to both approaches investigated in the present study.

5.4 Economic constraints

Apart from socio-cultural and ecological factors, two economic constraints are of particular relevance to the runoff irrigation scenarios investigated here.

Investment capital

Any use of runoff irrigation systems implies a certain level of initial investment. In the scenarios investigated, costs between 127,000 and 1,400,000 KSh arise before the trees yield any benefits. Turkana social organization and division of labor do not allow for large-scale investments, although traditional structures are breaking up. In general, a lack of financial capital favors less expensive water harvesting structures that can be built with manual labor, such as the micro-catchment scenario presented here. However, as many Turkana (especially women) need to use their manual labor for satisfying daily needs, they will expect to be reimbursed ahead of the realization of fruit tree harvests. **Currently, a lack of investment capital represents the single most important economic constraint to adopting runoff irrigation techniques.**

Market constraints

Production of fruit would mainly be geared towards the local market. Therefore, market constraints are also important. An extensive production of fruit in runoff irrigation systems would go beyond the market volume in Kakuma. For example, if papaya were able to reach a market share of 30% of all fruit consumed locally, the yields produced in 2.5 macro-catchment or 36.6 micro-catchment systems as described in this study would saturate this market. **Consequently, although the scenarios investigated could provide income to a number of people, the potential for runoff irrigation to reduce the pressure on natural resources around Kakuma is limited.**

Another market constraint pertains to the refugee camp itself. The local market for fruit largely depends on the presence of the refugee camp, and with it the feasibility of producing fruit commercially in Kakuma. The long-term prospects for the land use technique outlined in this work are clearly connected to the standard of living of the local population.

5.5 Improvement of traditional agriculture

The traditional rainfed system of the Turkana yields only a small profit that could be increased by the irrigation concepts presented in this study. All three species in the macro-catchment system as well as papaya in micro-catchments yield a higher profit than traditional rainfed agriculture. At the same time, opportunistic sorghum farming has evolved as a way to generate benefits with low costs and therefore reduce potential losses to a minimum. In contrast, efforts to build irrigation structures always imply financial risks. **Interestingly, while runoff irrigation ecologically reduces risks (of crop failure), economically, the opposite appears to be true.**

5.6 Outlook: runoff irrigation in tropical drylands of developing countries

Turkana settlement in Kakuma resembles a situation found throughout many drylands in developing countries. This chapter attempts to draw some general conclusions concerning the applicability of runoff irrigation in similar environments.

Essentially, runoff irrigation is a tool to optimize resource use. Runoff irrigation pays off because fixed costs (building the structures) can be written off over several years and because harvest benefits exceed variable costs for maintenance. Two factors were shown to be essential for profitability: (1) the availability of cheap labor to build and maintain the structures, and (2) the capability of the project to realize benefits rapidly and reliably. The extent to which these key factors can be found in other localities will determine the transferability of the results presented here.

Evidence of this study suggests that economies of scale exert considerable leverage concerning the profitability of runoff irrigation systems. On the other hand, experience gathered in past decades clearly showed the problematic nature of large-scale approaches to irrigation in drylands (ERUKUDI 1993). In many cases there, social organization and the availability of resources did not support large but only small-scale approaches to irrigation agriculture. **The tradeoff between profitability and feasibility constitutes a major difficulty for runoff irrigation projects.**

If the societal structures of the population in drylands change even more dramatically in the future, the need and acceptability of runoff irrigation may be different, as well. Projections of future developments for smallholder agriculture also in arid regions were not discussed in this work, but warrant further research.

Chapter 6

Ausführliche deutsche Zusammenfassung

6.1 Hintergrund und Fragestellung

Weltweit läßt sich eine zunehmende Seßhaftwerdung von Nomaden beobachten. Das gilt auch für die Turkana, einen nomadischen Stamm im ariden Nordwesten Kenias, bei denen der Kontakt mit der modernen Zivilisation zu einschneidenden Veränderungen ihrer Lebensweise geführt hat. Für diejenigen Turkana, die sich in der Nähe von Siedlungen niederließen, gewann gegenüber der traditionellen Viehwirtschaft vor allem der Handel mit Holzprodukten an Bedeutung. Die Kombination aus hoher Besiedlungsdichte einerseits und extensiver Nutzung natürlicher Ressourcen andererseits führte jedoch zu einer Überbelastung des fragilen Ökosystems, was Desertifikationseffekte und Hungersnöte zur Folge hatte. Diese Situation ist durchaus vergleichbar mit anderen Trockengebieten in Entwicklungsländern.
Einer der praktizierten Ansätze, diesem Problem zu begegnen, besteht darin, sogenannte Runoff-Bewässerungssysteme[44] einzuführen. Diese Bewässerungssysteme stauen den durch Starkregenereignisse erzeugten Oberflächenabfluß auf, um dieses Wasser zu landwirtschaftlichen Zwecken zu nutzen. Obwohl die Runoff-Bewässerung ökologisch nachweislich effektiv ist, haben die Turkana das System bisher kaum akzeptiert. Neben kulturellen Aspekten spielen dabei auch ökonomische Gründe eine Rolle.
Diese Arbeit untersucht in einer Kosten-Nutzen Analyse ein neuartiges Konzept, Fruchtbäume in Runoff-Systemen anzupflanzen, um den Nutzen für die lokale Bevölkerung zu maximieren. Im Rahmen einer Fallstudie wurde die folgende Fragestellung bearbeitet:

Würde es sich für die Turkana unter den lokalen Rahmenbedingungen lohnen, Fruchtbäume in Runoff-Systemen anzupflanzen?

Die Studie wurde in Kakuma im Norden des Turkana-Distriktes durchgeführt, wo sich Turkana in der Nähe eines Aufnahmelagers für Bürgerkriegsflüchtlinge angesiedelt haben.

6.2 Theorie und Methodik

Die lokale Situation wurde durch Marktstudien und Befragungen erfaßt und daraus Eingangsparameter für die Kosten-Nutzen-Berechnungen abgeleitet. Elementare ökologische Modellierung diente der Detaillierung der Szenarien. Für die Simulation der zu erwartende Ernteerträge wurden Literaturdaten mit lokalen Verkaufspreisen kombiniert. Im Rahmen der Investitionsrechnungen wurden Barwert, Nutzen-Kosten-Verhältnis und interner Zinsfuß als Entscheidungskriterien herangezogen. Eine Sensitivitätsanalyse wurde durchgeführt, um die relative Bedeutung der einzelnen Einflußfaktoren zu ermitteln, die Auswirkungen bestimmter Parameterabweichungen auf die Entscheidungskriterien zu untersuchen und eine Gesamtfehlerabschätzung zu ermöglichen.

6.3 Basisdaten und Szenarioentwicklung

Im Rahmen der Analyse wurden zunächst die lokalen Faktormärkte betrachtet. Die monetäre Bewertung der Arbeitszeit erfolgte hierbei anhand alternativer Beschäftigungsmöglichkeiten. Desweiteren wurden die Verfügbarkeit von Land und die Zeitpräferenz der lokalen Bevölkerung untersucht. Aus Kapitalopportunitätskosten und Risikoerwägungen ergab sich eine Diskontrate von 30% p.a., die auf einen Zeithorizont von 15 Jahren Anwendung fand.

Um die Kosten für die Etablierung der Bewässerungssysteme zu kalkulieren, wurden eine Reihe von hypothetischen Szenarien aufgestellt, die auf lokalen Pilotprojekten beruhen. Dabei wurden drei Obstbaumspezies (Mango, Guave, Papaya) in zwei unterschiedlichen Bewässerungssystemen (Micro- und Macrocatchments) untersucht.

Microcatchment-Systeme bestehen aus einer Anzahl halbkreisförmiger Erdwälle, die den Oberflächenabluß eines flachen Hanges auffangen. Jedes Catchment ist dabei so dimensioniert, daß es den Wasserbedarf eines einzelnen Baumes deckt, der an die Basis des Walls gepflanzt wird. Die für ausreichenden Wasserzufluß benötigte Fläche hängt einerseits von klimatischen Faktoren und der Bodenbeschaffenheit, andererseits auch von der Evapotranspiration der Fruchtbäume ab.

[44] Gebräuchlich ist auch der deutsche Ausdruck "Sturzwasserbewässerungssysteme".

Im Macrocatchment-System leitet man das Wasser aus einer natürlichen, von Regenwasser gespeisten Abflußrinne über ein System von Kanälen in eine Erdvertiefung, in der dann die Obstbaumplantage errichtet wird. Das Wasserangebot hängt hierbei primär vom Einzugsgebiet des Vorfluters ab, der das Bewässerungssystem speist.

Vergleichend mit dem Bewässerungsszenarien wurde in dieser Studie außerdem der traditionelle Sorghumanbau der Turkana untersucht, der von einigen Gruppen als Teil einer agropastoralistischen Lebensweise betrieben wird.

6.4 Ergebnisse

Im Microcatchment-Szenario erweist sich lediglich der Anbau von Papaya als profitabel. Grundsätzlich stehen den hohen Kosten, bedingt vor allem durch den beträchtlichen Wartungsaufwand, eine niedrige Pflanzdichte und dementsprechend geringe Erträge gegenüber. Die Papaya hat hier gegenüber den anderen Arten Vorteile aufgrund ihres geringeren Wasserbedarfs. Desweiteren lassen sich bei den Mango- und Guavenbäumen erst nach mehreren Jahren relevante Umsätze durch den Verkauf der Früchte erzielen, was sich wegen der hohen Diskontrate nachteilig auf die Profitabilität auswirkt.

Im Macrocatchment-Szenario erwirtschaften alle drei Arten einen substantiellen Profit, wobei wiederum mit den Papayabäumen nach allen drei Entscheidungskriterien die besten Ergebnisse erzielt werden. Die weit höhere Anzahl der Bäume, die in diesem Bewässerungssystem gepflanzt werden kann, überkompensiert den gegenüber dem Microcatchment-Szenario höheren Initialaufwand.

Die traditionelle Sorghumkultur der Turkana ermöglichst demgegenüber nur einen geringen Profit, realisiert diesen jedoch im Vergleich zu einer Obstbaumplantage wesentlich schneller.

Der ökonomische Hauptnachteil der untersuchten Bewässerungssysteme liegt darin, daß in erheblichem Maße Investitionen notwendig sind, die zum großen Teil als Vorleistung erbracht werden müssen. Diese Einschränkung gilt in besonderem Maße für das Macrocatchment-Szenario, für das Finanzkapital und Landmaschinen vonnöten sind. Die erfolgreiche Implementierung größerer Bewässerungsprojekte erfordert darüber hinaus einen Grad sozialer Organisation, der derzeit bei den Turkana nicht vorhanden ist.

6.5 Schlußfolgerung und Ausblick

In der vorliegenden Arbeit erwies sich die Kosten-Nutzen-Analyse als geeignetes Werkzeug, um den Entscheidungsprozeß der lokalen Bevölkerung zu simulieren. Die drei Entscheidungskriterien gestatteten die Beurteilung der Profitabilität sowohl nach absoluten als auch nach relativen Maßstäben. Die Sensitivitätsanalyse erlaubte eine sinnvolle Detailuntersuchung der Rechenergebnisse.

Es wurde gezeigt, daß eine Obstproduktion mit Hilfe von Runoff-Bewässerung in Kakuma profitabel wäre und auf die traditionellen Landnutzungstechniken aufbauen und diese verbessern könnte. Eine Papayakultur erbringt die höchste Rendite der drei untersuchten Arten. Im Vergleich der Szenarien ist das Macrocatchment-System zwar rentabler, benötigt aber erhebliche Anfangsinvestitionen. Die bisherigen Erfahrungen mit Bewässerungssystemen in Kenia legen nahe, daß hier ein Konflikt zwischen den "Economies of Scale" und ökonomischer Machbarkeit im Sinne des Vorhandenseins von Investitionskapital besteht.

Entscheidend für die Ökonomie eines Landnutzungssystems ist zum einen ein möglichst niedriger Aufwand für seine Etablierung und Wartung und zum anderen die Fähigkeit des Systems, Nutzen für den Anwender schnell und zuverlässig zu generieren. Das Extremklima von Trockengebieten wie dem Turkana-Distrikt stellt an diese Zuverlässigkeit hohe Ansprüche. Obwohl die Bewässerungstechnik ökologisch das Risiko von Mißernten verringert, erhöht sie doch das ökonomische Risiko, investierte Ressourcen zu verlieren.

Chapter 7

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Computer software

EndNote, ISI Research Soft

Excel 97, Microsoft Corp.

Photo Editor, Microsoft Corp.

Power Point 97, Microsoft Corp.

SigmaPlot 4.01, SPSS Inc.

Word 97, Microsoft Corp.

Annex 1

Description and yield data of mango, guava and papaya

Mango (*Mangifera indica* L.)

Mango belongs to the family of the *Anacardiaceae* and is one of the most popular tropical fruits. Mango probably originated in the Indo-Burma region and grows wild in the forests of India (PURSEGLOVE 1979). It is naturally adapted to the tropical lowland forests (up to 1600m) where it has been cultivated for the last 4000 years.

The evergreen tree varies in height (6-20m) and shape, depending on the cultivar. Nearly evergreen leaves (2.5-10cm long) are borne in rosettes at the tips of the branches. Mango prefers day temperatures between 20° and 26°C and is drought resistant. A well-drained and fertile soil (pH 5.5-7.5) is desirable (GRADY 1996).

A large number of mango varieties exist, delivering fruits ranging from the size of a plum to over 2.5 kg in weight (VAN EA 1992). Flavor ranges from very sweet to tart. Ripe fruits are eaten raw as a dessert fruit and used to manufacture juice, squash, jam and preserves.

Harvest starts 2 to 3 years after planting, again depending on the cultivar. Grafted trees are known to start producing early. After 8 to 10 years, mango reaches economic yields. Mango trees can grow very old, with even 300-year old individuals known to bear fruit (MORTON 1987).

The following list summarizes the yield data on Mango (compare table 3.3 in chapter 3.3.9).

Yield data mango

a) Typical annual yield:

	128 kg / tree	"Tropics"	(AIC 1984)
	186 kg / tree	Kenya	(GRADY 1996)
	287 kg / tree	"Tropics"	(VAN EA 1992)
	246 kg / tree	Kenya	(WESSELER 1996)
	349 kg / tree	Florida	(MORTON 1987)
average:	239 kg / tree		

b) Yield growth [in % of maximum yield] (GRADY 1996)

year 1:	0%	year 5:	42.8%
year 2:	0%	year 6:	73.5%
year 3:	3.5%	year 7:	91.6%
year 4:	24.5%	year 8+:	100.0%

c) Mango prices in Kakuma 24.6 ± 2.9 KSh/kg
(source: author's own data, n=10)

Guava (*Psidium guajava* L.)

The guava, member of the *Myrtaceae* family, is native in tropical America, and has been cultivated in many other tropical and subtropical countries. It can be found from sea level up to 2100m, indicating that the Guava has adapted to a wide range of soils and climatic conditions.

Trees reach a maximum height of 10m, with evergreen, opposite, oval-elliptic leaves (7-15cm long). Guava trees are sensitive to cold weather conditions, but grow successfully on soils that vary from sandy to heavy loam with a pH range of 4.5 to 8. Temporary waterlogging and climates with marked dry seasons are tolerated (GRADY 1996). Seeds are frequently propagated by birds and guava can be found growing wild in many places.

A number of superior cultivars are suitable for both processing and fresh consumption. The fruit is usually small, but specimen of 10cm diameter weighing more than 650g have been produced (GRADY, 1996). As with mango, the flavor of the fruit differs from sweet to highly acidic. Guava is eaten raw and cooked, and is sold canned and as juice or syrup.

Guava can start fruiting 1 to 2 years after planting, if the climate is favorable. It delivers two crops per year, and economic yields are reached after 6 to 8 years.

Yield data guava

a) Typical annual yield:	154 kg / tree	Kenya	(local guava tree)
	147 kg / tree	Kenya	(GRADY 1996)
	48 kg / tree	"Tropics"	(WESSELER 1996)
	61 kg / tree	India	(MORTON 1987)
average:	103 kg / tree		

b) Yield growth [in % of maximum yield] (GRADY 1996)

year 1:	0%	year 4:	30.2%
year 2:	6.1%	year 5:	84.7%
year 3:	10.5%	year 6+:	100.0%

c) Guava prices in Kakuma 31.9 ± 2.4 KSh/kg
(source: author's own data, n=5)

Papaya (*Carica papaya* L.)

The papaya, also known as pawpaw or tree melon, is a member of the *Caricaceae* family. Originated in tropical America, it is now grown in many other tropical and subtropical countries. Botanically, the papaya is a large herb lacking a woody tissue.

The plant grows fast and may reach a height of 8-10m, but it is short-lived and produces economic quantities only for a few years. Leaves emerging spirally can be up to 1m long and are deeply divided into segments and subsegments (MORTON 1987). Papaya is best grown at low elevations where evenly warm climatic conditions (20-25°C) lead to optimal fruiting. Locations receiving an annual rainfall of 1000-1500mm are ideal for cultivation. Papaya requires well-drained and fertile soils (pH range 6-7 is considered best) (GRADY 1996).

The ovoid fruit can weigh up to 2 kg each, but fruits of 250g-400g are preferred for export purposes. Although papayas are mostly eaten fresh, the fruit can also be used to produce papain which is an enzyme used against indigestion or to tenderize meat.

Papaya can start to bear fruit already one year after planting, sustaining high yields for two years. After three to four years, papaya plantations are usually uprooted and replanted, as yields decrease and the trees become too tall for economical harvesting

Yield data papaya

a) Typical annual yield:	89 kg / tree	Kenya	(local papaya plantation)
	60 kg / tree	Kenya	(GRADY 1996)
	60 kg / tree	"Tropics"	(WESSELER 1996)
	67 kg / tree	"Tropics"	(VAN EA 1992)
	71 kg / tree	"Tropics"	(AIC 1984)
	61 kg / tree	n.d.	(MORTON 1987)
average:	68 kg / tree		

b) Yield growth [in % of maximum yield] (GRADY 1996)

year 1:	0%	year 4:	74.5%
year 2:	100.0%	year 5:	55.8%
year 3:	89.1%	year 6:	27.9%

c) Papaya prices in Kakuma 37.8 ± 18.5 KSh/kg
(source: author's own data, n=8)

Annex 2

Relationship between bund size and working time for semi-circular bunds

The working time necessary to build semi-circular bunds[45] depends on the bund size. In this study, the bund diameter was chosen according to the water requirements computed for the fruit trees. Large bunds harvest more water and retain a higher water level within the bunds. Therefore, their bund walls have to be build both higher and wider than the walls for smaller bunds.

In order to obtain a relationship between bund size and construction time, local measurements were combined with data put together by REIJ et al. for differently sized bunds (Table A2.1). Figure A2.1 plots the bund diameter against the construction time. A regression curve $y=ax^b$ was fitted to the data, allowing prediction of the construction time for the bund sizes used in this study.

[45]No difference is made here between semi-circular and trapezoidal bunds. Trapezoidal bunds are usually preferred for row crops, while semi-circular bunds are better suited to concentrate runoff on a single spot and are therefore more suitable for trees. The construction process for both approaches is very similar.

Table A2.1 Construction time for different bund diameters of micro-catchments (semi-circular bunds, trapezoidal bunds, v-shaped bunds).

Location	Type of bund	Bund diameter [m]	Construction time [hrs]	Source
Kakuma, Kenya	Semi-circular bunds	6	2.40	avg. timekeeping (n=14)
Kakuma, Kenya	Trapezoidal bunds	40	77.63	avg. timekeeping (n=4)
Turkana District, Kenya	Semi-circular bunds	15	8.89	REIJ et al. (1998)
Turkana District, Kenya	V-shaped bunds	6.4	4.00	REIJ et al. (1998)
Sanmatenga province, Burkina Faso	semi-circular bunds	1	0.44	REIJ et al. (1998)
Tahoua District, Niger	semi-circular bunds	2	0.63	REIJ et al. (1998)

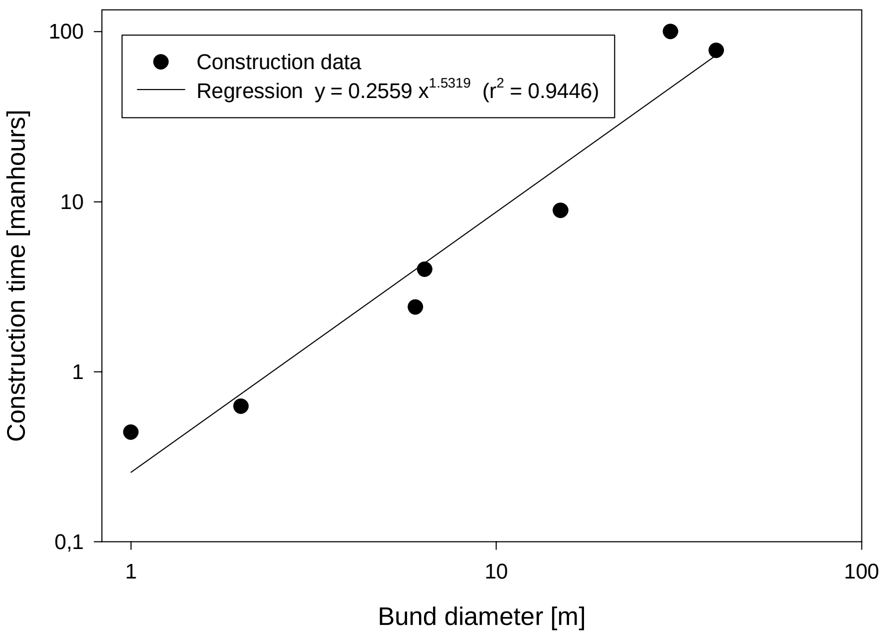

Fig. A2.1 Relationship between bund diameter and construction time for micro-catchments (semi-circular bunds, trapezoidal bunds, V-shaped bunds); double logarithmic scale, regression type $y=a \cdot x^b$. Source: author's own data and REIJ et al. (1998).

Annex 3

Interest rate based on herd growth calculations

In this study, an interest rate was calculated based on the development of an exemplary flock of goats[46] in one year. We assume that the flock is bought at t = 0 and sold at t = 1 year, including the offspring produced during that year. The internal rate of return of this "project" is equal to the interest rate expected from livestock keeping. Estimates for herd growth given by three Turkana elders (EKENO pers. comm.) were used as input parameters. Additional benefits arise from milk production of the does, while costs have to take into account the labor necessary to maintain the herd. RUNGE (1998) gives an estimate of the working time necessary to maintain a small herd of 20 goats in West Pokot district, northern Kenya. This working time was valued according to labor costs used in this study. Table A3.1 provides an overview, a calculation spreadsheet can be found in Annex 5.

In contrast to these estimates, LITTLE & LESLIE (1999) assume a realistic herd doubling time for goats of 3 to 5 years. This takes into account both the offspring produced and the mortality of the mature goats. Conducting the above calculations with this growth rate yields an effective interest rate of 22 to 33% (average 26%).

[46] Although the Turkana possess other livestock as well, sheep and goats are by far the most important species in Kakuma.

Table A3.1 Herd growth for a small flock (20 animals) of goats in Kakuma, northern Kenya; costs and benefits without discounting, internal rate of return.

	Herd growth assumed by Turkana elders			
	62%	100%	120%	94% (average)
Cost of buying herd of 20 animals (avg. value per animal 788 KSh) [KSh]	15750	15750	15750	15750
Cost of Labor[47] [KSh]	1733	1733	1733	1733
Total costs without discounting [KSh]	17483	17483	17483	17483
Revenues from selling immature young stock (avg. value per animal 467 KSh) [KSh]	5785	9330	11196	8770
Value of milk[48] [KSh]	3000	3000	3000	3000
Revenues from selling original herd (mortality = 20% per year) [KSh]	12600	12600	12600	12600
Total benefits without discounting [KSh]	21385	24930	26796	24370
Internal rate of return[49] [%]	26	49	61	45

[47] 56 working days child (55 KSh each), 6 working days adult (27.5 KSh each) (data adapted from RUNGE (1998))

[48] Estimate, depends on the number of does and kids in the herd

[49] The revenues from selling stock were discounted with t = 1 year, the value of milk and the labor costs with t = 0.5 years

Annex 4

Survey questionnaire

A small survey was conducted to complement information gathered on labor costs and interest rates. Respondents were to estimate a salary for their own working time as well as interest rates based on money transactions. The questions were phrased as follows:

a) Willingness to work:

Someone from your community you don’t know very well asks you to work for him. He says it takes 1 day. How much should he pay you for that?

b) Time preference[50]:

1. You have the choice of 100 KSh now or 100 KSh two years from now, which one do you prefer. What about 110 KSh? 120 KSh? ...

2. You lend 100 Shillings to someone you don't know very well. He pays you back one year later. How much do you think he should pay you back?

[50] For the results displayed in Table 3.5, the average of the two answers was taken.

Annex 5

Tables

This part contains a selection of tables. In terms of the cost-benefit calculations, an exemplary table is provided here, referring to the standard conditions of the mango scenario in micro-catchments. The subsequent list provides an overview.

a) Printed tables

b) Tables on CD-ROM

The tables for the cost-benefit analyses for the other scenarios can be found on the attached CD-ROM (see the list of files on page vii).