Farming Practices and Crop Production

An Exploratory Study of Farming Strategies vs. Maize-production in Makanya Village, Tanzania

Peter Berglund

MSc Thesis in Soil Science

Supervisor (handledare): Abraham Joel

Institutionen för markvetenskap
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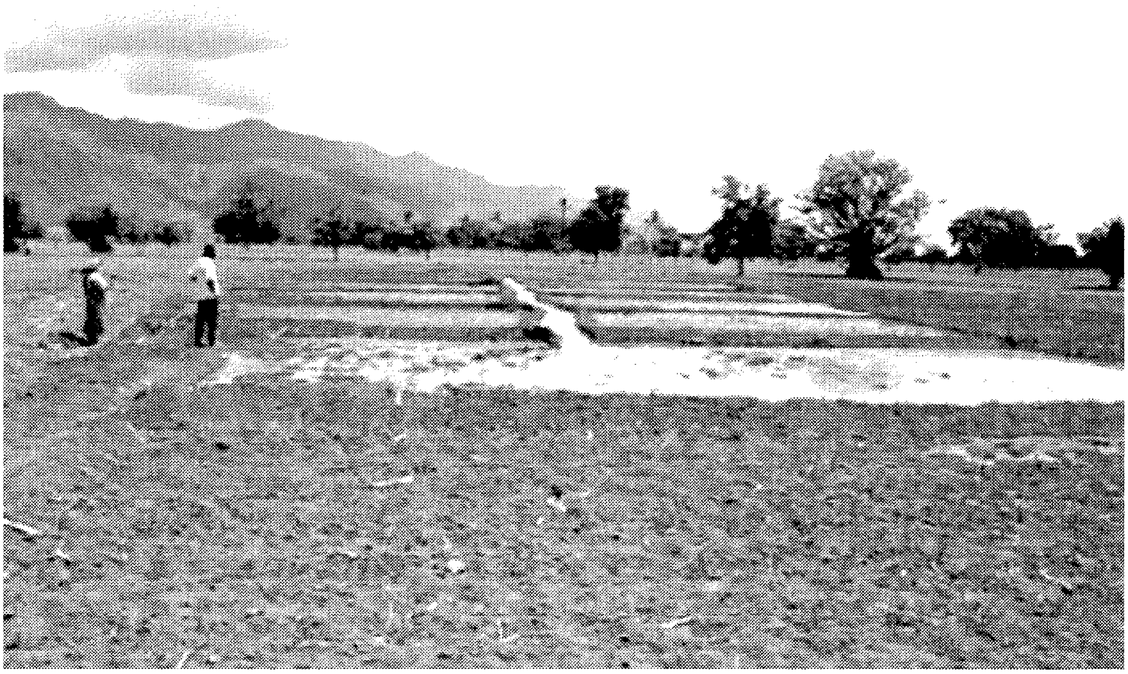

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PREFACE

The preparation of this Master Thesis could not have been possible without the help from several persons and organisations. First of all I would like to direct my thanks to RELMA (Regional Land Management Unit) in Nairobi for their hospitality, support, transport and advises and in specific Sören Damgaard-Larsen, George Njoroge and Faith Bwona. Other equally important persons in the project area (Makanya, Tanzania) were my interpreter Mr Mjenga, PhD student Abeid Msangi, Mr Ludovic, Mr Ali and all the farmers of Makanya village that gave me invaluable information and support. In addition, an NGO organisation called SAIPRO in Same district that helped me with the logistics and other issues deserves gratitude.

At SUA (Sokoine University of Agriculture) in Morogoro I would like to send my thanks to Professor Nuhu Hatibu, Professor Rwehumbiza and Dr. Tumbo and all the rest of the people at SUA that guided me trough arduous times. I would also like to direct my thanks to my colleague in Tanzania Sofia Billvik and to Björn Nylander for support when I was stuck in the field. Lat but not least, I send my appreciation to my supervisor Dr. Abraham Joel at the Swedish University of Agriculture (SLU) for his expert advises.

Uppsala, January, 2004

Peter Berglund

The photograph on the front-page shows the irrigation system used in Makanya, Tanzania. (Photograph by the author, 2002)

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ABSTRACT

The main objective of this thesis is to examine and discuss if an improved farming strategy, in an arid area, affects the maize yield significantly. The basis for the discussion is the "case study" and the spatial (GIS)-analysis of the farming practices and the maize yields. The study was performed in Makanya in the north of Tanzania.

The result from the GIS-analysis indicates that there is a high correlation between water supply and biomass production. The GIS-maps also show that the farmers adjacent the river outlet (high water supply) invests more resources in farming methods compared to farmers far from the outlet. The increase of yield due to farmer input, where the water is insufficient, is however minor. The results from the "case study" illustrate nevertheless the importance of proper farming strategies if the water supply is sufficient.

The findings do not verify the general statements about a significant increase in biomass production with the introduction of judicious farming methods. This is due to the water constraints in Makanya.

Keywords: *Agriculture, maize-production, farming practices, yield, GIS, water constrain, runoff, semi-arid, Tanzania*

REFERAT

Huvudsyftet med denna uppsats är undersöka och diskutera huruvida en förbättrad odlingsteknik/strategi, i en arid region, påverkar skördeavkastningen påtagligt. Diskussionen baseras på dels en "fall studie" samt de rumsliga (GIS)-analyserna av odlingsmetoder och avkastningmönster i Makanya. Studien utfördes i Makanya i norra Tanzania.

Resultatet från GIS-studien visar att det finns en tydlig koppling mellan vattentillgång och biomassa produktion. GIS-kartorna indikerar också att bönder i närheten av den flodens utlopp (hög vattentillgång) investerar mer resurser i diverse odlingsmetoder till skillnad från bönder långt från utloppet. En skördeökning beroende på intensiv odling i områden där vattentillgången är låg kan emellertid inte noteras. Resultatet från "fall studien" illustrerar emellertid hur viktigt olika odlingstekniker är för en framgångrik odling *om* vattentillgången är adekvat.

Dessa resultat kan inte verifiera de generella påståendena att en skördeökning automatiskt medföljer en intensivare odling. Detta beror på den prekära vattensituationen i Makanya.

Nyckelord: *Jordbruk, majsproduktion, odlingsmetoder, skörd, GIS, vattenbrist, avrinning, semi-arid, Tanzania*

1. INTRODUCTION

The local production of food is essential for the people in developing countries. Difficulties concerning food production are, however, a common and recurring problem in this part of the world. There are many complex reasons why this food deficit occurs, but according to several studies, one constraint is poor farming practices (Hudson, 1995; Rockström, 2001; Mzirai et al, 2002; Stewart et al., 2003). Farming practices or land husbandry refers to many different aspects of agriculture production, from rainwater harvesting to tillage techniques.

According to a report, published by Food and Agriculture Organization (FAO, 1978), the potential yield of common crops (e.g. maize, millet) is 2-5 times higher compared to the average production in Africa today, which indicates low productivity. Hudson (1995) claims that food production could increase drastically with the introduction of simple farming methods, but more research is required. The above statements make this topic interesting. The focus of this thesis is thus the biomass production, and the farming strategies employed in a semi-arid region in the north of Tanzania.

The area of research is Makanya village in Same district, Kilimanjaro region, Tanzania.

Objective

The primary objective of this study is to examine:

- The farming practices, yield of maize and climate in Makanya.
- The spatial distribution of farmer input and yield of maize (GIS/GPS).

The data is collected in order to discuss the correlation between farmer input, water supply and yield (Case Study and GIS).

The ambition is also that this study will generate a deeper understanding of the problem in Makanya lowland, specifically, and for other dry lowland areas, in general.

2. LITERATURE REVIEW AND BACKGROUND

Farming practices and yield

The key objective of this thesis is the farming practices and crop production in Makanya village, Tanzania. Farming practices refer to a wide variety of techniques or farming methods. Some examples are rainwater harvesting, soil tilling, harrowing, planting density, mulching or input of fertilizer. The examined farming practices in this thesis are described in detail in chapter 3 (social study). The farmer inputs aim to improve the soil structure, the soil fertility, reduce weed growth, etc. in order to increase the biomass production (Fogelfors, 2001). In developing countries, farmer inputs are relatively low compared to industrial countries. In this context, many researchers or organizations argue for a more intense use of the cultivated areas in the developing world to improve the yields (FAO, 1978; Hudson, 1995; Barron et al., 1999; SWMRG, 1999; Rockström, 2001; Fox & Rockström, 2000). Intense farming refers to a higher input of different farming practices.

According to many studies from Eastern Africa, the average yield of cereals is below 1 ton of grain per hectare, while experimental stations in Africa consistently demonstrate yields of over 5 tons per hectare (Hudson, 1995). Hudson (1995) claims that the potential yield of common crops in sub-Saharan Africa can be increased two to four times by the judicious use of off-farm inputs such as chemical fertilizers, appropriate farm tools, improved varieties etc. Table (1) from Food and Agriculture Organization (FAO) (1978) illustrates this statement.

Table 1. Yield potential of crops* (ton/ha)

Land capability	Input	Millet	Sorghum	Maize	Bean
Very suitable	Low	0.9	1.1	1.6	0.7
	High	3.5	4.6	6.4	3.0
Suitable	Low	0.6	0.8	1.0	0.4
	High	1.8	3.0	4.2	2.0
Marginal	Low	0.3	0.4	0.5	0.2
	High	1.2	1.5	2.1	1.0

* From FAO (1978)

According to Table 1, the maize yield could increase 4 times with high farmer input if the capability of the land is marginal. In a recent report from a semi-arid region in the north of Tanzania shows that the yields of maize and paddy rice increased significantly with different rainwater harvesting systems (SWMRG, 2000). Other field studies in Burkina Faso and Kenya show the possibility of doubling or even tripling the yield using rainwater management (Fox & Rockström, 2000). A study from a dryland area in Texas, USA (2003) illustrates the effect of other farming practices (e.g. tilling techniques, crop rotation) for biomass production. The results show a clear correlation between adequate farming operations and crop performance (Harman, 2003). These field results and general statements are investigated and discussed further in chapter four and five according to the situation in Makanya lowland.

Tanzania and agriculture

Tanzania is relatively large country (945,000 km2) situated in the east part of the African continent, immediately below the equator. The population of Tanzania has increased drastically during the twentieth century and now exceeds 34 million people (2002). The official capital is Dodoma, but the largest and most economically important city is Dar-es Salaam.

Tanzania is one of the poorest countries in the world with a GNP of less then 230 US dollars. Almost 85 % of the population of Tanzania is employed in the agriculture sector (Mzirai et.al. 2002), but although the vast majority is active in the agricultural production, the yields are low. The low production of food in Tanzania caused by several factors: e.g., poor technical input (mainly hand-hoe), many farmers are located in geographically marginal areas (low rainfall, poor soils, lack of labor) (Mzirai, et al., 2002). This is mainly a consequence of an increase in land pressure, more areas that are marginal are used for agriculture purposes and much of this land is located in the arid or semi-arid belts where rain falls irregularly (Bouwman, 1997). The main cash crops in Tanzania are tea, coffee, tobacco and spices and the food crops are mainly maize, cassava, rice, wheat and bananas.

Makanya

Makanya village is situated in Same district, *Kilimanjaro region* in the north of Tanzania at an elevation of 680 meters above sea level (see Figure 1).

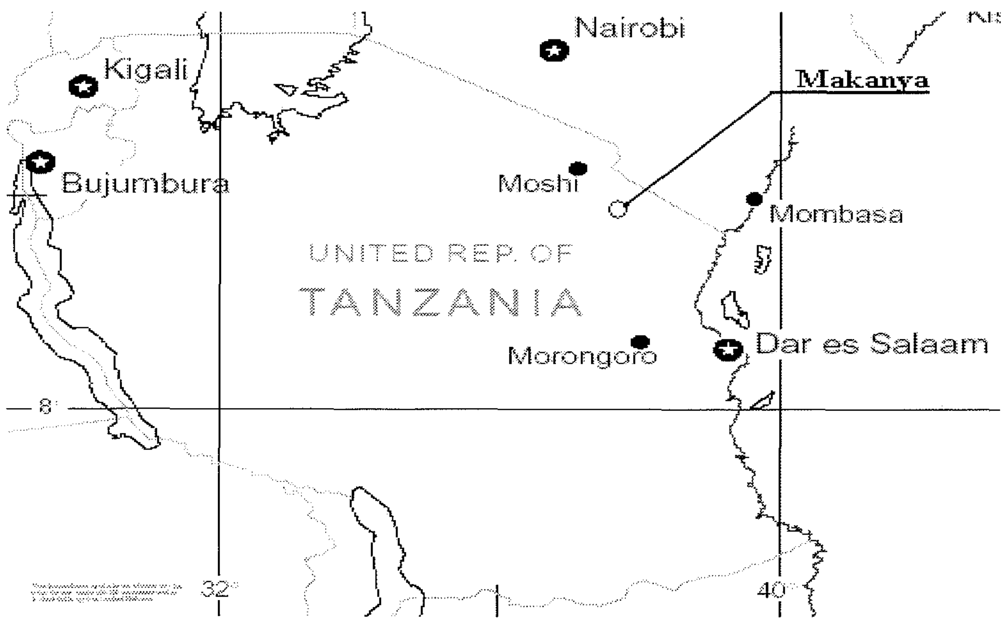


Figure 1. The village of Makanya is located in the white circle in the map above. The Kilimanjaro region stretches from the Kenyan border north of Moshi to the south of Makanya village (UN, 2003).

Climate

There are three main agro-ecological zones in Kilimanjaro region (Morungu, 2003):

I. The characteristics of the lowland zone are unreliable rainfall and a low population density. Periods with no rainfall during the growing season are a common phenomenon and average annual temperatures are over 30°C. The main crops are maize and cassava and on irrigated land rice and sugarcane. There is also extensive livestock keeping in this zone.

II. High rainfall amount and a high population density characterize the middle belt. The annual temperature varies between 25-30°C and the main crops are coffee and bananas.

III. The third zone or the upper belt has a very high yearly precipitation and temperatures below 20°C. This zone is neither suitable for agriculture nor livestock keeping.

Makanya village is located in the lowland zone and categorized as semi-arid, due to high potential evaporation and low rainfall amount (Forest, Grassland and Drylands, 2003). Two kilometers to the east of the village is the *Pare* mountain chain ranges, from Kilimanjaro Mountain in the north to Tanga district in the south. The slopes of the Pare Mountain belong to the middle belt with a relatively high precipitation. The farmers in the lowland regions utilize some of the runoff water from the slope of the Pare Mountain. The water in Makanya River originates from this source.

In Makanya and the northeast part of Tanzania, the rain mainly falls during the two rainy seasons. The long rains (Masika) season start in March and continue until May, than there is a period of short rainfall November until December (Mvuli) (Rockström, 2001). During both of the growing seasons, the absence of rain for a short period of varying length (often 3-4 weeks) is a common phenomenon. The period with no rain is refered to as a dry spell (Rockström, 2001).

The soil and the river

The Makanya River that occasionally provides the cultivated area of Makanya with water also affects the soils. The alluvial material transported in the river mainly consists of clay and silt particles, but the upper horizon of the soil adjacent the river contains more coarse particles. According to the soil map of Tanzania the soil of Makanya classified is as a *Fluvisol (mollic)* (FAO legend) (Majule, 2003). The development of a Fluvisol (Fl) originates from alluvial deposits and the parent material is mostly recent and varies between medium- and fine-textured fluviatile. The soil is periodically flooded in alluvial plains. The soil is well distributed globally and occurs on all continents and in all kinds of climates, from semi-arid to perhumid climate zones. The light texture of the fluvisols can have a variety of structures (granular, crumb, subangular and blocky). The horizons are normally weakly developed. The predominant colour is brown (aerated) and/or grey (waterlogged). The fluvisols are used for a wide range of crops and grazing, but drainage systems and/or irrigation are often required (Driessen & Dudal, 1991). The soil map is generalized and further investigations are necessary to establish a more accurate soil classification for Makanya lowland.

Figure 2 shows the river and the agricultural land of Makanya.

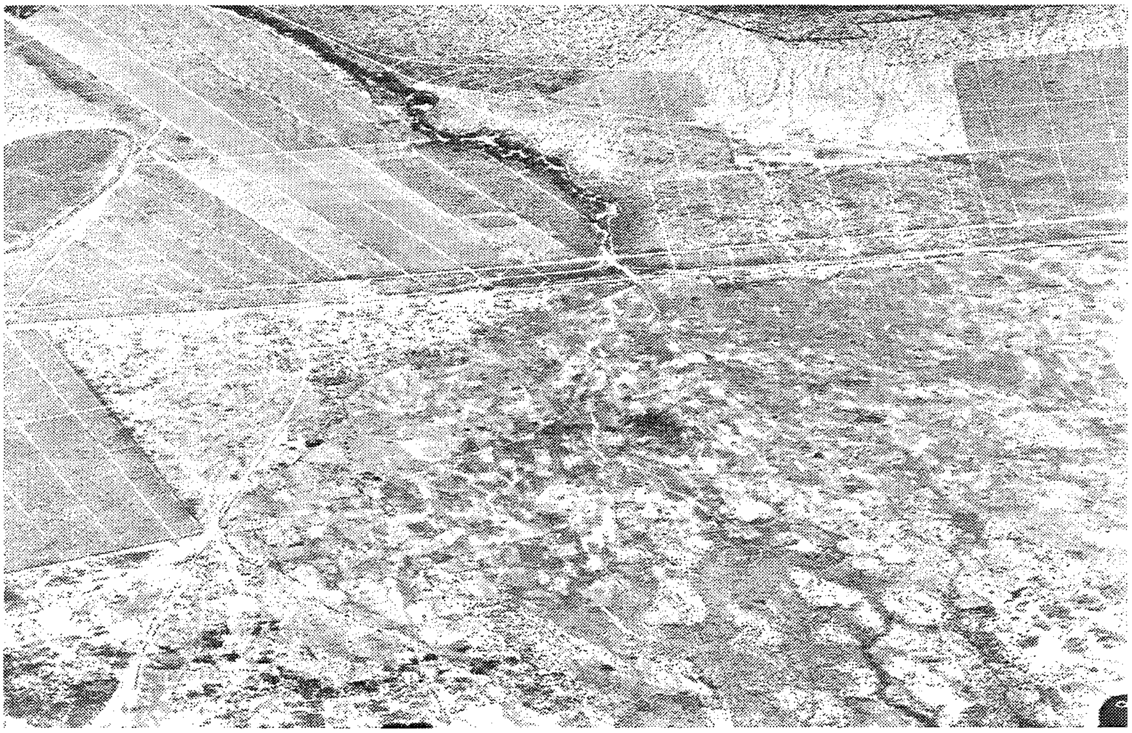


Figure 2. Aerial photo of Makanya area (From Sokoine University of Agriculture, 1996).

The well-arranged sisal plantation is shown in the upper part of the picture. The settlements and the village are located in the middle part of the picture to the left. The central divide in white signifies the river. The cultivated area is homogenous with scattered plots belonging to different farmers. Further, east of the village is the Pare Mountain ranges, but they are not distinguishable.

The socio-economic situation

There are approximately 3000-4000 people living in the Makanya village with an average family size of 10-15 members. The main source of revenue is agriculture and livestock. The total agriculture land is 400-500 hectares. In the south section of the village is where, the main part of the cultivated land is situated. Most of the inhabitants live in the central part of Makanya. The land has been cultivated since the late nineteenth century and the population and village are continuously expanding. The large sisal plantation (Hasan Estate) to the east of the village provides some labor opportunities for the people in the area.

A lime mine is also situated adjacent to the village (9 km west) where mostly young inhabitants work. This bestows some financial support to the village. The tribe and tribe-language that dominates the area is called *Pare.* Around half of the population belongs to the Christian church and the others are Muslims.

3. METHOD AND MATERIAL

The chapter below describes the methods and materials used in this study, but also a brief theoretical discussion about some of the methods employed. The chapter includes two subchapters. First is the method and materials used to *collect* the data described (Collection of data I, II). The next part explains the method and materials concerning the *analysis* of the data (Analysis of data I, II).

Collection of data I

The interviews and examination concerned 46 farmers. The farmers were chosen "randomly". During the Mvuli season of 2002, many farmers worked on their fields and during ten days of transportation in the cultivated area, we detected several farmers. The farmers that were detected during these ten days were interviewed and their fields were examined.

Below are the *three* approaches used to collect the information concerning the farming practices, yield and climates schematically illustrated.

Social
- Farming practices and yield (interviews)

Technical
- Farming practices (crop density and height of bunds)
- Rainfall and evaporation data

Direct observation
- Farming practices (furrow maintenance, basin sizes, agroforestry, windbreaks, planting pits, the leveling of the soil)

<u>Social investigation</u>

A social study involves conducting interviews or/and studying social patterns in a society. There are many different approaches due to different scientific disciplines and objectives (Lustig, 1998). Because of the nature of this study interviews were a suitable option were in combination with the other methods. To conduct interviews requires knowledge about the area of research and a strictly prepared methodology (Patton, 1980). Patton (1980) also claims that in the beginning of every interview occasion certain information addressed to the informant is required. The information shall contain: What will be asked? Whom is the information for? The handling of the information and the purpose and the use of the information received.

There is a large variation of interviewing approaches (Patton, 1980; Halvorsen, 1992). In this quantitative study, the optimal solution was a mixture of two types of interviewing techniques: A *standardized* and a *structured* version. The approaches that characterize the former technique are the use of questions determined in advance and these questions are probed in some depth. The latter represents a technique with already fixed answer alternatives. The strengths with these semi-structured interviews are the comparability between the respondents and simple data analysis. Another strength is the possibility of translating the data figures (Patton, 1980).

The weakness of the interviews method is the low flexibility and variability that affects the answers given. Standardized wording might constrain the naturalness in answering the questions. Another negative aspect is that the informant might perceive the interview as mechanistic and irrelevant and that could be reflecting the answers (Patton, 1980; Halvorsen, 1992).

The majority of the received data from the social investigations was translated into figures, which could be problematic. To translate the information into figures sometimes requires a relatively arbitrary interpretation or valuation. This factor has to be accounted for as it cannot be eliminated.

The structured and semi-structured interviews focused on farming practices and yield. The questionnaire is attached in the end of the report (see appendix 1). The questions mainly deal with average yield, main crop, size of farm, the use of manure, fertilizer or pesticides, etc (see description below):

Average yield:	The interviewed farmer estimates the production of maize (bags/acre).
Inorganic fertilizer:	The use of synthetic fertilizer (yes/no).
Manure:	The use of manure from animals (yes/no).
Compost:	The use of compost. Compost is a term for crop residues that are gathered and sometimes mixed with other organic matter for development of nutrient rich material. This rich material could then be applied to the soil (yes/no).
Pesticides:	(Includes herbicides/insecticides). A pesticide is any substance or mixture of substances intended for: preventing, destroying, repelling, or mitigating any pest. Pests are living organisms that exists where they are not wanted or that cause damage to crops or humans or other animals (yes/no).
Sub-soiling	Refers to a mixture of the under horizon with the topsoil (more then 30 cm) (yes/no).
Intercropping/ Crop rotation:	Mixing crops or intercropping means that the peasant, in the same season, mixes crops (ex. maize plus sorghum). Crop rotation refers to a system where the farmer uses different crops each season. The first season the farmer could grow maize followed by millet the next season. This agriculture system repeats itself the following seasons (yes/no).
Ground cover:	Ground cover protects the soil from the solar radiation and thus prevents soil evaporation (yes/no).

Weeding: The number of weeding events per season.

Other questions were also asked that will not be used in the GIS-analysis, but in some cases in the discussion part. These questions were:

Rainfall (intensity, amount, distribution over the year)
Flooding events in general
Flooding events to receive an adequate yield
Infiltration rate
Problems working with the soil
Soil type
Seeding and harvest
Maize variety
Tilling techniques

Technical investigations

Crop density and height of bunds
The crop density and the height of the bunds were examined with a measurement tape. The densities of the crops were measured according to the number of plants per planting pit and the total amount of plants per hectare. Only a few selected areas were examined in the farmer field and thus the accuracy could be un-complete.

The height of the bunds that some of the farmers use to hinder the water from leaving the field was also examined with a measurement tape. Low or non-existing bunds are regarded as poor farming practices.

Rainfall and evaporation data
The precipitation data was measured on a rain gauge and collected by the employees of the sisal plantation called *Hasan Estate*. This rain data was gathered during the field study. The potential evaporation data was measured at Same meteorological station, 45 km north of Makanya.

Direct observations

During the interviews in the field, the farming practices were also examined through direct observations:

Agroforestry (no/yes)
Windbreaks (no/yes)
Planting pits (no/yes)

Also other management factors were recorded directly according to a value system explained in Table 2.

Table 2. Classification of furrow maintenance, basin sizes and the soil levelling

Management technique	Classification		
Furrow maintenance	Good	Moderate	Poor
Basin sizes	Good (< 100m2)	Moderate (Large: 200-400m2)	Poor (None)
Levelling	Good	Moderate	Poor

Good maintenance of the furrows refers to clearing the furrows from vegetation and constructing a deep and functional furrow system. The basin sizes are of significance for the water losses. The basins size affects the uniformity of the water flow and thus deep percolation water losses. The water flow in a small basin is more controllable and thus preferable. The levelling of the soil is also important for the water flow. A well-levelled soil could dramatically reduce the water losses (FAO, 1971).

Collection of data II

In the case study the production of maize and the management techniques employed between two farmers were compared. In order to eliminate other factors except the soil and water management techniques it is necessary to examine also the soil condition (soil texture, structure and fertility). These factors, and why they are important for crop-production, are highlighted below.

Soil profiles

Soil is a complex matter, which has been formed over time by the action of climate, organisms and parent material (McRae, 1988). The branch of soil science that primarily is concerned with these processes is called pedology. Soil conditions will greatly affect the crop growth potential.

Soil consists of both organic and mineral fractions and the former is derived from decaying plants and animals. The latter comes from rocks, sand, clay, silt and minerals salts (Dupriez & DeLeener, 1990). The mineral fraction is also subdivided in terms of particle size into stone, sand, silt and clay and this is referred to as soil texture. The soil structure is the aggregate that is formed in the soil (Mcrae, 1988). All the above factors, in combination with soil fertility, will affect the plant growth potential.

Soil structure generally signifies the combination of soil particles into aggregates or peds, which is thus not the same as soil texture. Between these units (aggregates), there are channels and these channels define the size and shape of the units. The durability of the units is also used in describing the soil structure (e.g. granular or crumb structure). Soil structure is determined by: texture, organic content, chemical properties, weather, biological activity and agricultural practices (Fitzpatrick, 1980; Mcrae, 1988). Soil structure is important for the formation of both micro and macro pores. These pores will partly determine the water holding capacity and the water flows in the soil.

In an agricultural soil, a common phenomenon is the so called "hard pans". The pans are usually formed precisely under the plough pan or layer due to mechanical forces (Davies et al., 1993). This characteristic could influence the crop performance drastically because the root penetration is hampered. The plant growth potential is therefore dependent on the structure of the soil.

There are several methods to determine the soil structure, but generally the soil is exposed in pits 100-150 cm deep on representative sites (Bohlin & Messing, 1981). During the examination, some characteristically differentiated layers or bands occur, called horizons. These horizons have arisen by the action of soil forming processes (Fitzpatrick, 1980). A lot of information can be revealed during an excavation about the soil properties. Food and agriculture organization (FAO) has prepared a manual for soil examination (FAO, 1990: Guidelines for soil description), which partly is used.

By digging three soil profiles, randomly chosen, on each farm the soil structure was established. Six profiles were dug and analysed using FAO: s "Guidelines for soil description" (1990), except soil reaction.

Soil sampling

As noted above, soil texture is the particle sizes of a soil. The fraction of different soil particles will affect plant growth because the soil texture influences soil properties. A clay soil will have different qualities compared to a sand soil. In a clay soil, the water holding capacity is much higher in contrast to a sand soil, a property that dramatically could affect plant growth (Dupriez & DeLeener, 1990). The nutrient status is often better in a clay soil due to its higher cation exchange capacity (CEC), which is an important factor for crop performance (McRae, 1988). In Figure 3, the texture classes according to proportions of the three components (sand, silt, clay) are explained.

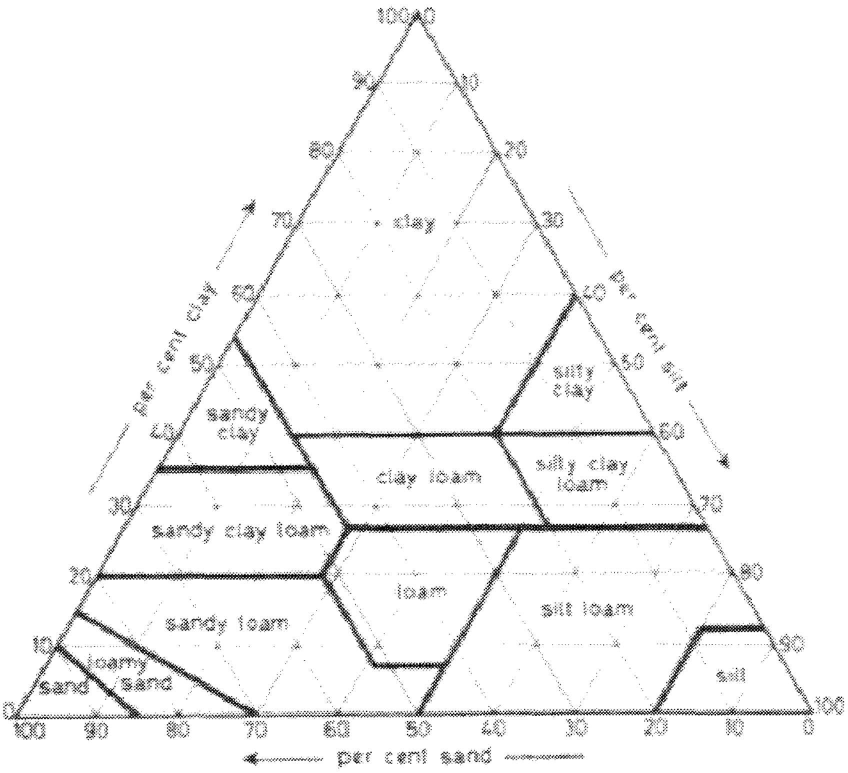


Figure 3. The soil texture triangle, relating particle size distribution to texture classes (McRae, 1988, page 13)

Soil texture can be determined in the laboratory by measuring the percentage of the different components in a time consuming process. Other more simple methods with acceptable accuracy could also be employed (McRae, 1988).

Ten soil samples from each farmer in the case study were gathered. The samples were collected from the soil surface, 20 cm and 40 cm below the surface (using a soil auger). The texture classes of these soil samples were analysed with two methods called "the rolling test" and "finger assessment".

According to Dr. Stuart McRae these methods have a sufficient accuracy for the determination of the soil texture (McRae, 1988). By mixing a soil sample with an adequate amount of water and then form a "worm" of the sample. It is possible to roughly determine the soil texture of the sample by bending the "worm" (see appendix 2 for the full test). If the worm cannot be bent then the content of sand is high and the opposite condition prevails if the worm is very bendable, that is high clay content.

The other method employed was "finger assessment". The principle is the same as for the method described above. By wetting a sample of soil and manipulating it between the fingers to assess the relative proportions of sand (feels gritty), silt (feels smooth and silky) and clay (feels sticky).

A soil with approximately equal proportions of each (feels doughy) is called loam (McRae, 1988). The sites were the samples were collected were randomly chosen.

Soil fertility

Soil fertility is the "status of a soil with respect to its ability to supply elements essential for plant growth without a toxic concentration of any element" (Foth & Ellis, 1997).

Plants derive most of their nutrients from the soluble minerals in the soil. The more plant available nutrients and reserves, the higher the soil fertility (McRae, 1988). Measuring the soil fertility over a large surface area is connected with several problems. First, the soil fertility could vary significantly both spatially and vertically, which makes it difficult to gather representative samples (LaMotte, 2002). Another problem is the extraction method used in the specific study. Different extracting methods will extract different amount of nutrients from the same soil sample. For an adequate fertility analysis, it is therefore necessary to combine the extraction method with crop performance and fertilizer response (McRae, 1988). Because of this, the method used has to be specified and the data has to be interpreted.

One of the substances that is most difficult to measure is the nitrogen amount as the content largely depends on the activities of the microorganisms and could vary notably over short periods of time (Foth & Ellis, 1997). Another source of information is farmer knowledge that should not be underestimated. The soil fertility will evidently affect the growth potential and is thus of importance for an accurate result.

Only a few representative samples were collected and analysed due to time-constraints. In total 20 samples were collected (10 on each farm) 20 cm below the surface using a soil auger. The device used was "La Motte" fertility kit. This instrument can analyse pH, macro- and micronutrients in the soil. The micronutrients were not measured in this study, rather some macronutrients and pH. The classification of a nutrient rich and poor soil is shown in Table 3, according to the instrument used.

Table 3. The fertility classification according to La Motte (2002)

	Nutrient (kg/ha)		
Class	Nitrogen (N)	Phosphorus (P)	Potassium (K)
Low	0-34	0-56	0-135
Medium	35-68	57-113	136-225
High	69+	114+	226+

The technique used to analyse the soil samples are described in La Motte Manual (La Motte Soil Test Kit, 2003). For the pH measurements the method is described in La Motte Handbook/Manual (La Motte, 2002).

Analysis of data I

The information from the collection of data I is systematically classified according to the tables below.

Farming practices

The farming practices are divided into three categories (data from the social/technical study and direct observations) to illustrate the use of *different* management techniques:

1. Soil management (Manure, compost, inorganic fertilizer, sub-soiling, the use of agro-forestry)
2. Water management (Earth bunds, basin sizes, deep planting pit, furrow maintenance)
3. Crop management (Pesticides, weeding events, windbreaks, crop rotation/mixing, crop cover)

Each framers total point are added together and explained in the tables below (Tables 4-6).

Table 4. The number of "soil management" points received for each farmer

Management	0	1	Points
Manure	No=0	Yes=1	0-1
Compost	No=0	Yes=1	0-1
Inorganic. fertilizer	No=0	Yes=1	0-1
Agroforestry	No=0	Yes=1	0-1
Subsoiling	No=0	Yes=1	0-1
			Sum*

* The total points per farmer (0-5).

Each question was answered with yes or no. The amount or the extent of each management technique was not investigated. The farmer receives 1 point if the specific management technique were used. These points are then added together (sum) and a high score indicates good soil management techniques employed for the current farmer. The next table (5) shows the classification of the water management techniques.

Table 5. The number of "water management" points received for each farmer

Management	0	1	2	Points
Earth bunds	None=0	Moderate=1	High=2	0-2
Basin sizes	Large=0	Medium=1	Small=2	0-2
Furrow maintenance	Marginal=0	Basic=1		0-1
Planting pits	No=0	Yes=1		0-1
				Sum*

* The total points per farmer (0-6).

The use of planting pits was examined through interviews (yes/no alternative). The other management factors were investigated either visually or technically. The maximum amount of points amounted was six if the farmer used high earth bunds (2 points), small basins (2 points), planting pit (1 point) and good furrow maintenance (1 point). The next table (6) illustrates how the use of crop management techniques was systemized and categorized.

Table 6. The number of "crop management" points for each farmer

Management	0	1	2	3	Points
Weeding events	None=0	1 time=1	2 times=2	3 times=3	0-3
Pesticides	No=0	Yes=1			0-1
Crop cover	No=0	Yes=1			0-1
Crop rotation	No=0	Yes=1			0-1
Windbreaks	No=0	Yes=1			0-1
					Sum*

* The total number of points per farmer (0-7).

The use of crop management techniques was examined through social investigations. The questions were formulated as a yes or no alternative, except weeding events (0-3 times). The maximum points are 7 if all questions were answered yes and the weeding events amounted to 3 times.

Because the input data is not equivalent, only the tendency could be visualized. The data is not equivalent because of several factors. One of them is that a farmer could claim that he/she employs a pesticide, but the amount or the quality of the substance unknown. This means that two farmers could claim that they use pesticides, but the effects could be quiet different. Another problem is the classification of the points. Some management techniques have a higher value, but this value does not always correlate to the real situation. This also means that 1 point in, for example, soil management does not correlate to 1 point in water management.

Analysis of data II

The data from the tables in chapter "analysis of data I" and the spatial location of each farmer input (GPS) are imported to the GIS-program.

GPS

The construction of the global positioning system (GPS) started in the middle of the 1980´s, via the American satellite position system (Eklundh & Arnberg, 2001). The system is composed of 24 satellites placed in 6 loops around the globe. The altitude is approximately 22000 km and the time of circulation is 12 hours. The signals from the satellites determine the position. There are two ways to measure the position with a GPS:

1) Absolute measurement
2) Relative measurement

Absolute measurement only requires one receiver and the accuracy is around 10-20 meters, depending on the quality of the receiver. This system is mainly employed in navigation contexts and is simple to use. The relative measurement is more complicated, but more precise. You need several receivers and at least one of them has to be placed on a known position. This procedure is called Differential GPS (DGPS) (Eklundh & Arnberg, 2000). An absolute measurement instrument is used in this study.

The position or coordinates of each field were saved on the GPS instrument (Garmin) and transferred to the GIS-program (Arc-GIS).

Geographical Information System (GIS)

GIS stands for geographical information system and is used for the spatial analysis of farmer input and yield. GIS has been developed from many different scientific disciplines and thus the definition varies. This should not be considered a negative aspect, instead it is an expression for the broad use of geographical information or data (Eklundh & Arnberg, 2000). In this thesis, the definition is as follows:

GIS is a computerized system for managing and visualizing geographical, technical and social information

With this definition, which is relatively similar to others, I would like to emphasize the value of GIS for visualizing data received from different sources: *Geographical* (e.g. the position of the sampling), *technical* (e.g. crop density) and *social* (e.g. interviews). A keyword in this study is the position or the geographical data received. This means that every object (e.g. yield) in the database has coordinates that indicate the global position (georeferencing).

The geographical position of the objects is central for the function of GIS and marks the line between other programs that handle maps (Eklundh & Arnberg, 2000). So how does GIS function then? There are some fundamental steps and they are mentioned here in connection to my study in Makanaya, Tanzania:

1. *Reading*: The system receives or acquires data from different primary sources. For example maps, GPS-receiver and text- and figure information from field investigations. This process is the first step and called digitalizing.
2. *Management of data*: The next step is the handling of the input data. The program systemizes the information received and here it is possible to modify and update the input data. In addition, functions to adapt the geometry in different layers of data to each other are feasible.
3. *Analyze*: All the information in different layers (e.g. yield and water management) and themes are analyzed. This could be as in my study overlapping of data layers to analyze the spatial correlation between yield and soil conservation techniques.
4. *Presentation*: The last step is the presentation or visualizing of the results. The information received is easily accessible for the user, but in my case the results have to be analyzed to detect the important factors that influence the production of food.

GIS and agriculture

Earlier research using GPS/GIS versus agriculture has mainly focused on precision agriculture (Cummins, 2003; Geoeurope, 2003; Fletcher, 2003, etc.). This means for example where to fertilize the field with the best results according to yield and soil data. In this study, the focus will be the correspondence between yield and management by using a GPS and a GIS-approach. GIS are used to identify sections with high production and the use of farmer input as a basis for discussion. The spatial distribution of yield is normally measured during harvest with some kind of yield-monitoring instrument (e.g. Basnet et al., 2000). Figure 4 below shows the result from one investigation. The black section indicates high production and the light grey area represents the section where the production is lower. The data was gathered through a deterministic approach (Roel & Plant, 2001).

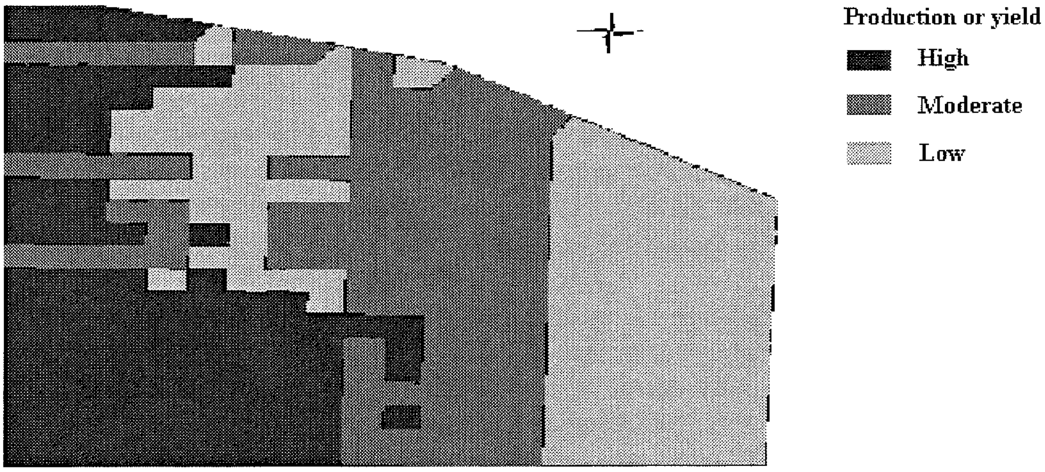


Figure 4. Illustrating how the yield data can be analyzed spatially (from Roel & Plant, 2001).

GIS-mapping
The GIS-program Arc-GIS will be used in this study. Arc-GIS consists of three modules: Arc-map (former arc-view), Arc-toolbox and Arc-catalog. The Arc-map module presents the maps and tables with coordinates and this will mainly be used. Arc-catalog and Arc-toolbox are used to manipulate and operate the maps (McCoy & Johnston, 2001). To present the data in a GIS-format it is necessary to translate the information into numbers or values (see farming practices above). The GIS-program shows the data on 3 different maps (soil management, water management and crop management). The spatial analysis of the data is based on the GPS-instrument.

The farmers of Makanya cultivate a homogenous area, but own different plots and uses different farming techniques or strategies. A spatial analysis of the input data visualises sections with high and low production and the spatial distribution of farmer input. A tool for studying spatial data is GIS. It is assumed that GIS is an adequate tool for visualising the spatial distribution of land husbandry and crop-production among the farmers in the area.

There are two main types of GIS-models for representing the reality: The *representation* and *process* models. The representation model is concerned with description of the objects in the landscape and the process model tries to analyse the representation data (modelling). This GIS-methodology used in this study is the former described and based on vector data. Vector is a data structure, used to store spatial data (University of Melbourne, 2003). The vector data from the study will be transferred into grid data. Grid data simply means that every object is represented by a square. The representation model attempts thus to capture the spatial relationship between objects in the landscape (University of Melbourne, 2003).

The grid data is then interpolated for predicting the values for a larger surface area from a limited number of sample points (the interviewed farmers). Interpolation of data provides a simple method of analysing large data from large areas. Data for generating these surfaces are usually collected though field sampling and surveying. Because of high cost and limited resource, data collection can be conducted only in selected point locations with limited numbers. In order to generate a continuous surface of a property (i.e. groundwater table), some kind of interpolation method has to be used to estimate surface values at those locations where no samples or measurements were taken (Hu, 2003). Interpolation could be divided into three further categories:

- *Inverse Distance Weighted (IDW)*: The cell values are estimated by averaging the values of sample data points near each cell. Some sample points or cells have a number or a value. The value will influence the adjacent cells according to the value and other sample points. This method does not employ any mathematical or statistical model in the interpolation process.

- *Kriging*: This method is available in the spatial analyst, a tool in the ArcMap program. This method is based on statistical models that include autocorrelation. Kriging weights the surrounding cells with values to derive a prediction for the unmeasured locations. The weights are based on three parameters: distance between measured points, the location of the predicted points and the overall spatial arrangement among the measured points.

- *Spline*: This method uses a mathematical function for predicting the unmeasured points or cells instead of a statistical model. This method is suitable for gently varying surfaces (elevation) and water table heights (McCoy & Johnston, 2001).

In comparison with other interpolation methods (Inverse Distance Weighted and Kriging) the spline interpolation shows the best results concerning homogenous areas and interconnections between measurement points with similar values (University of Tubingen, 2003). Each of these methods has its own advantages and disadvantages in terms of data interpolation. No one method works universally as the best method for all the data set. Selection of a particular method depends on the distribution of data points and the study objectives (Hu, 2003). The most suitable method in this study is IDW and the size of the raster data is set to 50 m. The average field size in Makanya accounts to 50x50m.

As noted above 46 randomly chosen farmers in the cultivated area have been interviewed and examined. The position of the field is saved on the GPS-instrument. This data in combination with the data from the survey are then systematically analysed in Excel and then transmitted to the GIS-program. According to Figure 5 the data is put into tables and then transferred into vector data. The classification of the values, except yield, is described under farming practices above.

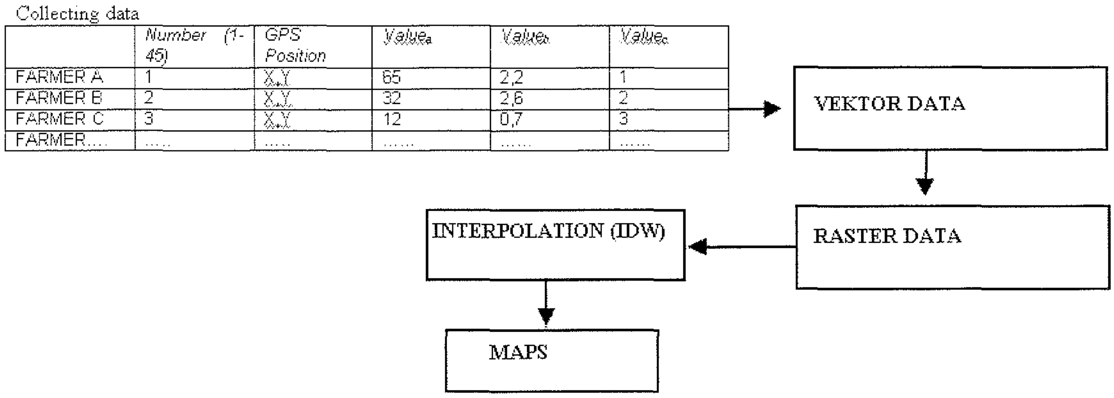


Figure 5. Illustrating the working-methodology used in the GIS-study.

Field methodology

Figure 6 summarizes the data and the methodology employed in this study.

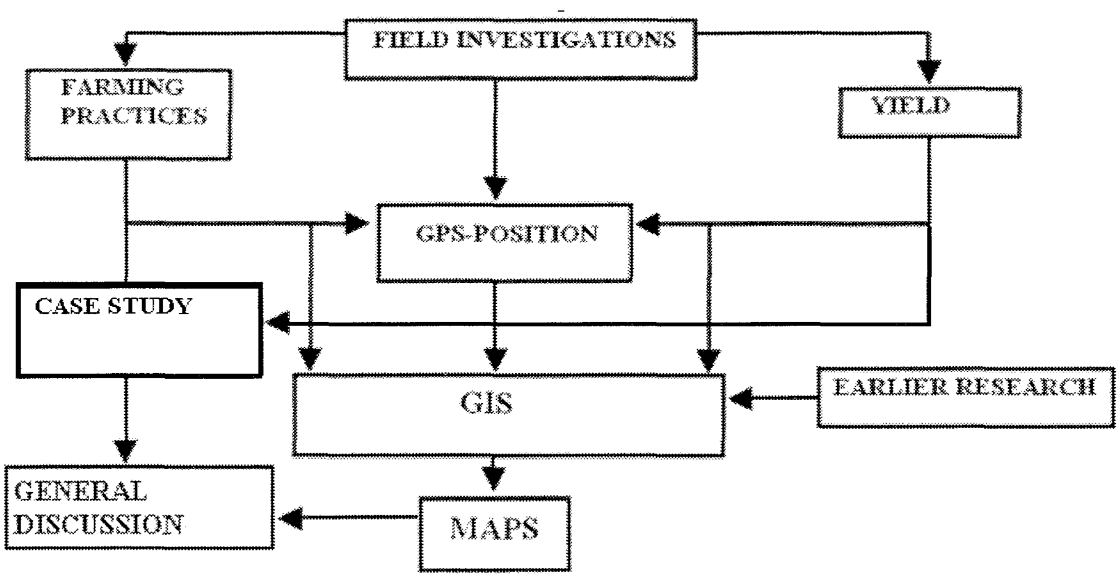


Figure 6. Summarizing the field methodology used in this study.

The collection of data was made through a social and a technical approach in combination with direct observations. The majority of the data and additional data (earlier research) were imported into the GIS-program. There is a direct arrow from farming practices that passes through the box "case study", to general discussion. This data is excluded from the GIS-approach because of its complexity. The map box indicates the result from the GIS-analyses. The boxes "case study" and "general discussion" are also results that are not presented in the GIS-format.

4. RESULTS

This chapter presents data from the social and the technical survey in combination with direct observations.

Climate and crop-water requirement

Rainfall and potential evaporation (PE)

The climate of Makanya is dry and hot as previously noted. With an average precipitation of less then 450 mm per year and a potential evaporation of around 2500 mm, the region could be classified as an extremely dry semi-arid area (Hasan Estate meteorological station, 2002; Same meteorological station, 2002). The average annual temperature is between 25-30 degrees Celsius. The Figures below present the precipitation and potential evaporation (PE) data on a monthly basis and a comparison between the two climate factors. Figure 7 illustrates the average rainfall per month in Makanya.

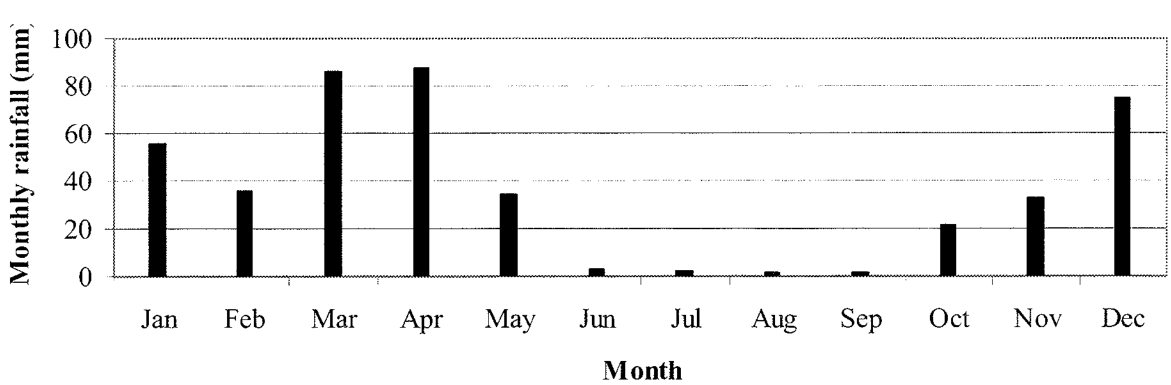


Figure 7. The average precipitation in Makanya per month in millimetres. Based on data from 1990-2002 (Hasan Estate meteorological station, 2002).

The most humid months in Makanya are March and April and during this period the total precipitation exceeds 170 mm. This is more than one third of the annual rainfall. The short rains (Mvuli) normally start in the end of October and ends in January. According to the rain data this season is not followed by a dry period before the Masika rain season initiates. The two seasons overlap each other. From June till the end of September the rainfall is almost absent. The yearly precipitation amounts to 440 mm.

The potential evaporation (PE) rate follows the same pattern. PE is measured in Same town, 45 km north of Makanya on a pan instrument. The pan evaporation measurements are made at a monitoring site, which are part of a weather station network. Pan evaporation typically overestimates the rate of evaporation from an open water body, but gives a good approximation (IGBP, 2003). In Figure 8 the PE data is presented.

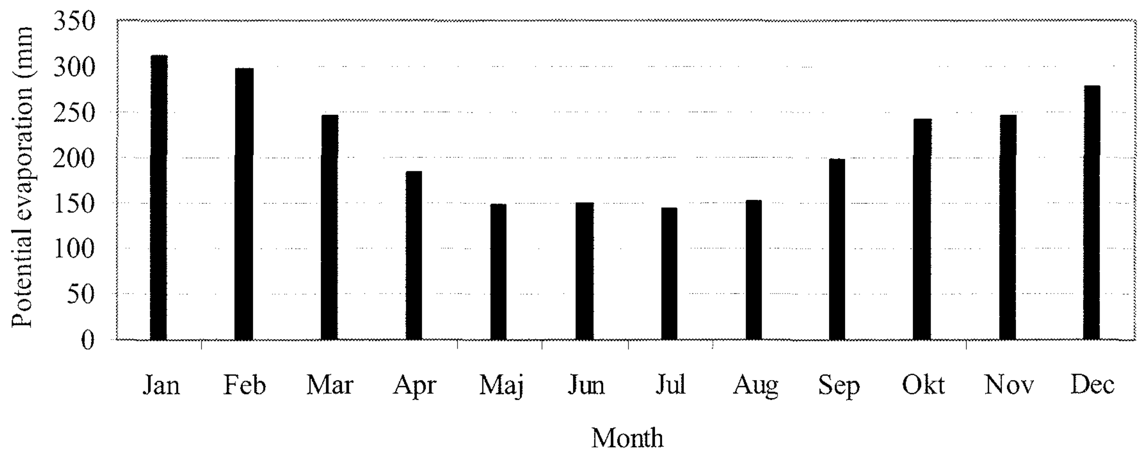


Figure 8. The potential evaporation in Same town 45 km north of Makanya.

The PE is measured in millimetres per month. The PE peaks in January and then decreases until May. There is a slight increase in June followed by the lowest PE rate in July. After July the PE increases gradually until January. A comparison with the monthly PE and the rainfall is illustrated in figure 9.

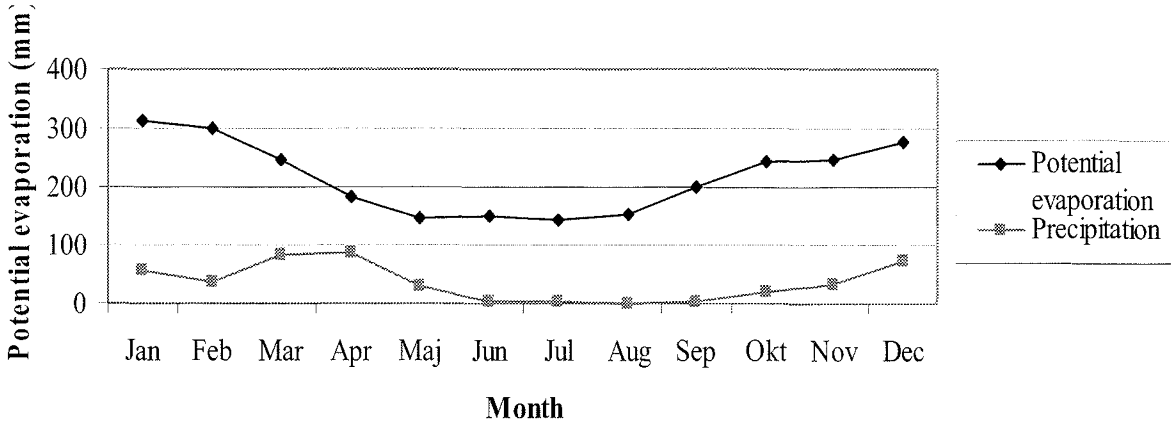


Figure 9. The correlation between potential evaporation (Same meteorological station) and rainfall in Makanya.

According to the diagram above the precipitation never exceeds the potential evaporation rate on a monthly basis. The least variation between PE and rainfall is in April and this gap increases steadily during the next months until February. On a daily basis the rainfall can exceed the PE.

Water and crop-water requirement

The biomass production is intermittently measured in yield/mm of rain or rain use efficiency (WRI, 2003). A high production with low annual rainfall indicates good farming practices (Hatibu & Mahoo, 2000). Rain use efficiency (RUE) is the ratio of net primary productivity to rainfall. The crop production in Makanya is relatively high considering the low precipitation. A study performed in Babati district, Tanzania, shows the relationship of yield and biomass production. This data is compared with the Makanya situation (see Table 7).

Table 7. Maize performance in Babati district* and Makanya

Location	Yield	Rainfall	
	kg/ha**	mm/year	kg/ha of maize per mm of rain
Makanya	2000	440	4.5
Babati	1460***	596	2.45

* From Hatibu & Mahoo, 2000.
** Per year (1 ton/season).
*** Average value from a number of seasons (1990-1997).

An efficient use of the water supply in Makanya could explain the high ratio in the Table above.

The main crop in Makanya, maize requires around 500-800 mm of water per season (Hatibu & Mahoo, 2000) and with an average precipitation of less then 200 mm per growing season, the situation becomes very problematic. Figure 10 shows the relation between precipitation and evapotranspiration (ET) for maize an average *Mvuli* season in Makanya.

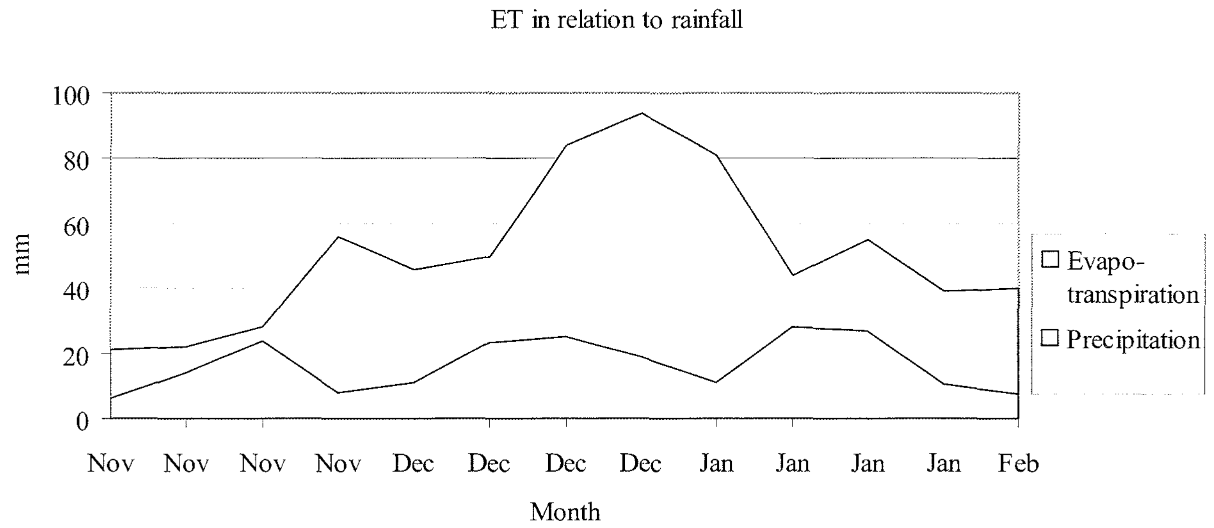


Figure 10. Illustrating the rainfall deficit for production of maize an average Mvuli season in Makanya.

Another source of water is the river that runs through the cultivated area. This water has to satisfy the ET requirement or the skew-scattered area in Figure above. This water is, however, seldom enough for cultivation of the whole area. During the field investigations in Makanya *Mvuli* season 2002, the crop-water deficit amounted to more than 250 mm for the examined area (including the water from the river) (Berglund & Billvik, 2003). Only 10-20 % of the farmers received a normal yield during the Mvuli season of 2002. The *Mvuli* season 2002 was relatively dry though, with a precipitation less than 150 mm and this circumstance in combination with a low flow in the river affected the yields very negative. Nevertheless, even during a normal or humid season a large part of the farmers do not produce sufficient amounts of maize. The areas adjacent the river are the only locations that could generate adequate or high yields for a majority of the seasons (Pers. comm., 2002).

The probability of an adequate yield during a 10 year period depends greatly on the position of the field or the plot. With the present situation a field situated close to the river outlet could receive an adequate yield 4-5 out of 10 years and a farmer situated far from the water source obtain a sufficient yield 1-2 out of 10 years (Pers. comm., 2002). According to Gommes & Houssiau (1991) study, performed in Tanzania is the potential yield of crops such as Sorghum achieved only 2-3 years out of ten, which resembles the figures from Makanya above. The data above illustrates the crop-water deficit in Makanya. Water is a key constrain for crop-production and the river that provides farmers with irrigation water is of great importance. The majority of the crop-water requirements derives from the river.

Farming practices

Figure 11 shows the results of the social study and the direct observations which excludes the weeding events, basin sizes and furrow maintenance (mainly from tables in chapter 3). The percent value signifies the fraction of the interviewed farmers. For example 22 % of the interviewed farmers use manure.

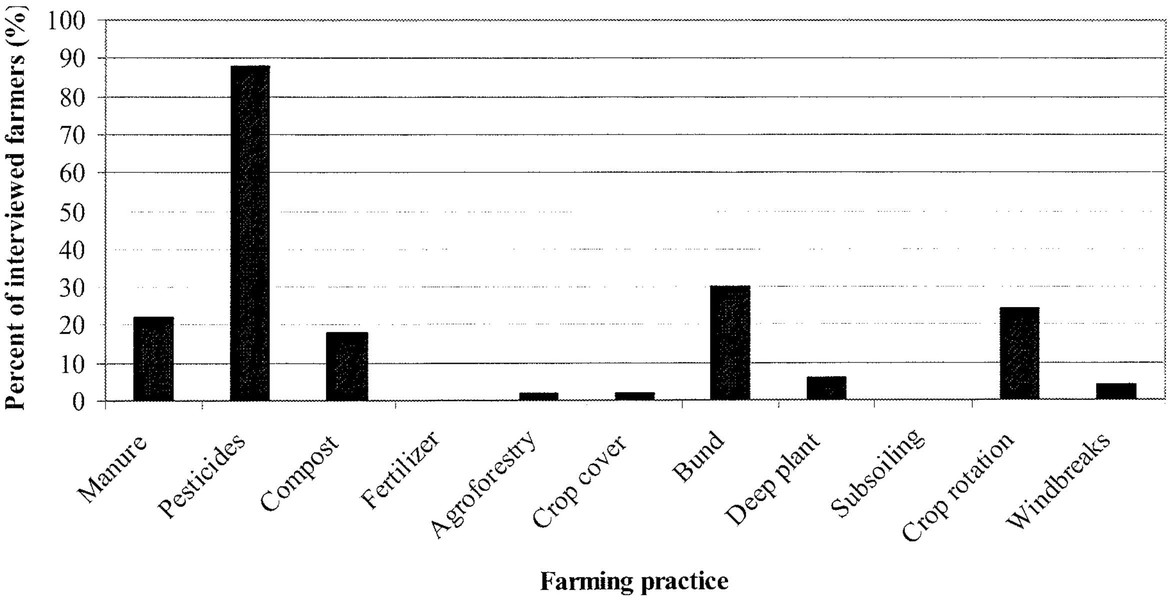


Figure 11. Illustrating the use of different management techniques in Makanya.

The data indicates that the use of different farming practices is relatively low. None of the farmers use inorganic fertilizer or sub-soiling. The employment of crop cover and agroforestry are also very low, although pesticides are a common practice. Over 80 % employ this farming strategy. This data will be further explained and used in the chapters below.

GIS-data

The GIS-maps below illustrate the spatial distribution of the farms, yield and farming practices. The GIS-data is divided into 9 maps:

1. Overview of Makanya area with the settlements, sisal farm and the agricultural area. Data from earlier research.
2. The river and other objects from earlier research. The river system, the Dar-Arusha road and railroad plus the power line are data from earlier research in the area.
3. Map one plus the position of the fields that have been used in the study.
4. The distribution of farmer input of soil management techniques.
5. The crop management techniques employed in Makanya area.
6. The input of water management techniques in Makanya.
7. Crop density of maize.
8. The spatial distribution of average yield of maize.
9. Comparison of the maps.

Bird view of Makanya area

Figure 12 illustrates the Makanya region from above (GIS-format). The demarcated area to the east of the figure symbolizes a part of the sisal farm. The light grey section in the north part represents a fraction of the settlements. The grey zone indicates the agriculture area.

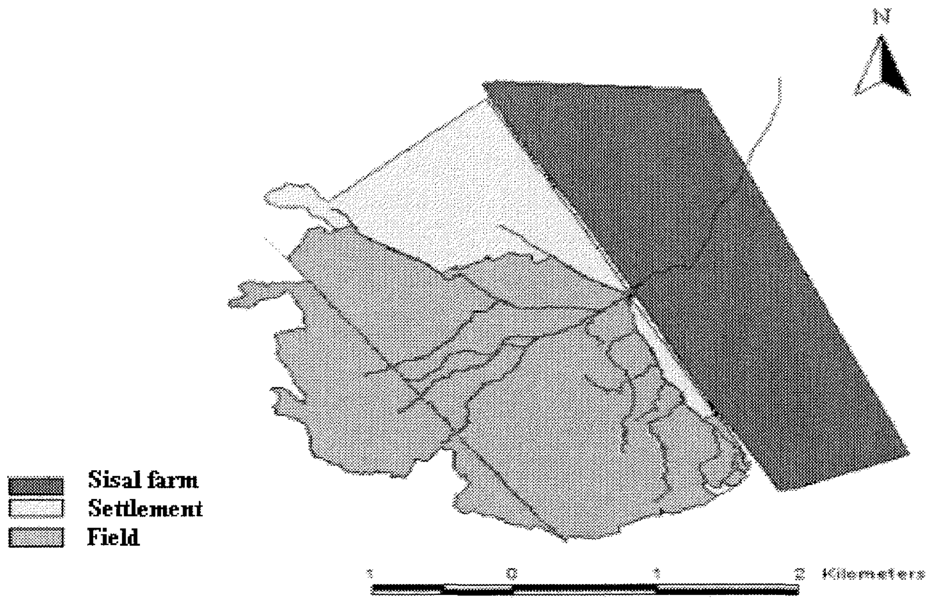


Figure 12. Showing the Makanya area from above (SWMRG, 1998).

The river of Makanya

The shape of the river is based on earlier data that was gathered in 1999. The power line could be seen to the left on Figure 13 and to the right the railroad and the road to Arusha are distinguishable. The line next the river is the railroad tracks. The canal stretches over the cultivated area, which forms an almost parallel trapeze.

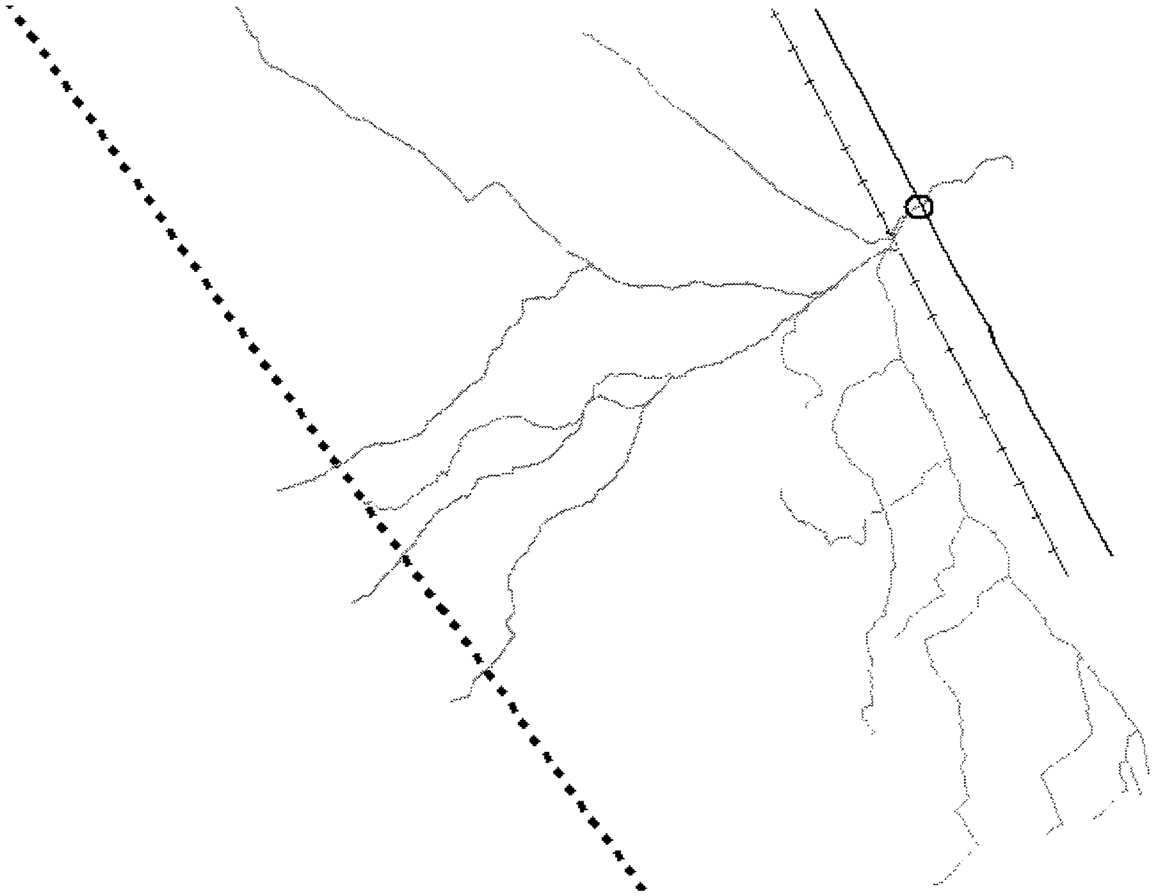


Figure 13. The river and the handmade channels in the study area. The central part of the Figure is the natural river. The scattered line to the left represents the power line. The railroad are marked with cross-symbols and the road is discernible to the right of the Figure (from SWMRG, 1998)

The river also distinguishes itself from natural rivers. The furrows or channels are mostly handmade. Only a minor fraction of the central parts of the river is natural. During high flows, the water is transported in this central divide to the *Pangea* River, 35 km to the east of the village. This seldom occurs as the water flow is normally very low and utilized by the people in the area. The last flooding event was during El Nino effect 1997-98 (Pers. comm., 2002). The scattered line to left of the outline of a power line.

The main irrigation channels are shown on the Figure above. The small irrigation furrows, that could not be seen, are distributed in the whole area and resemble a fine-meshed net. The railroad is the object adjacent the river. The Dar-Arusha road and the bridge over Makanya River are shown in the picture below (Figure 14) (the circle indicates the position of the photograph). When the water from the mountain saturates the soil in the river the flow processes initiates, however, much water is lost during the saturation phase. The average slope in the area is between 1-2 %.

Figure 14. The river outlet under the Dar-Arusha road during the dry season (Photograph by the author, 2002).

During the dry season from June until October, the river is completely dry. During the rain season the river, contains water a few times of varying length (1-7 days). The depth of the flow is normally between 1-2 feet (30-60 cm) (pers. comm., 2002). According to field investigations in the fall of 2002, the river contained useful or enough water 4 times in the Mvuli season. The flow was, however, low and stayed for 1-2 days only. The River contained water additionally 2 times, but the flow was to low and could not be employed by the farmers. This was catastrophic for most of the farmers because they normally receive the majority of the water via the river. Only a few of them had a normal yield. During a wet season, the situation is acceptable, but in the majority of the seasons, the water is not enough for the completely cultivated area of Makanya.

According to the farmers in the area, the last very good season that generated a high yield or maximum yield was during El Nino effect 1997-98. During this season, the water was abundant.

Some farmers claim that it was too much water, which lead to crop failure. The production in some areas amounted to 4-5 tons per hectare, which is high. The potential yield of maize is just over 9 tons per hectare under ideal conditions (soil, water, climate, etc.) (FAO, 1979). The farmers in the area also claim that the river was perennial approximately 30 years ago, but gradually the water in the river has decreased.

The catchment area that provides the river with water is very large and is situated in the Pare Mountains (see Figure 15).

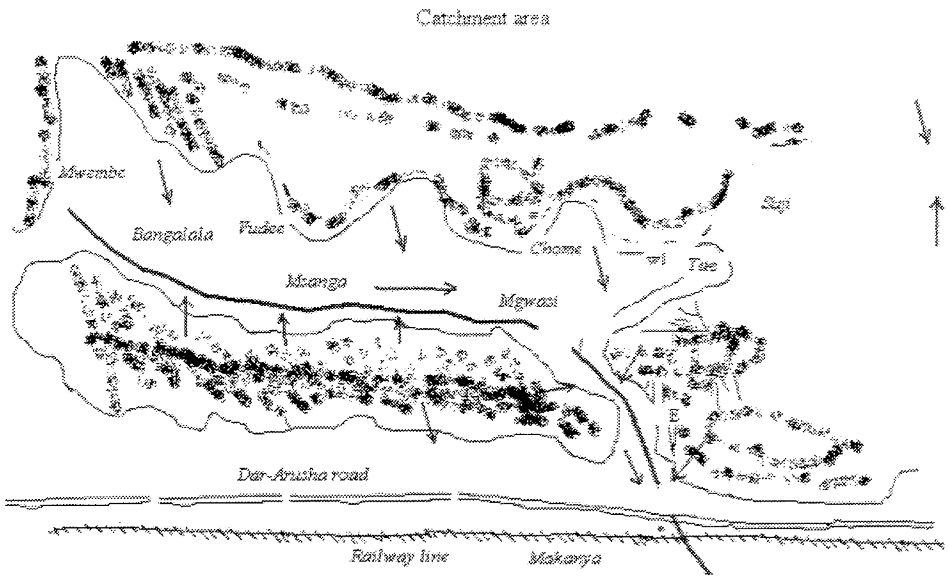


Figure 15. Illustrating the catchment area and the villages in the Pare Mountain that provides water to Makanya River.

The water situation is considerable better in this upland areas compared to Makanya lowland. The precipitation often exceeds 1000 mm per year (Msangi, 2002).

The location of the investigated fields

The position of the fields that was investigated in the study is presented in Figure 16.

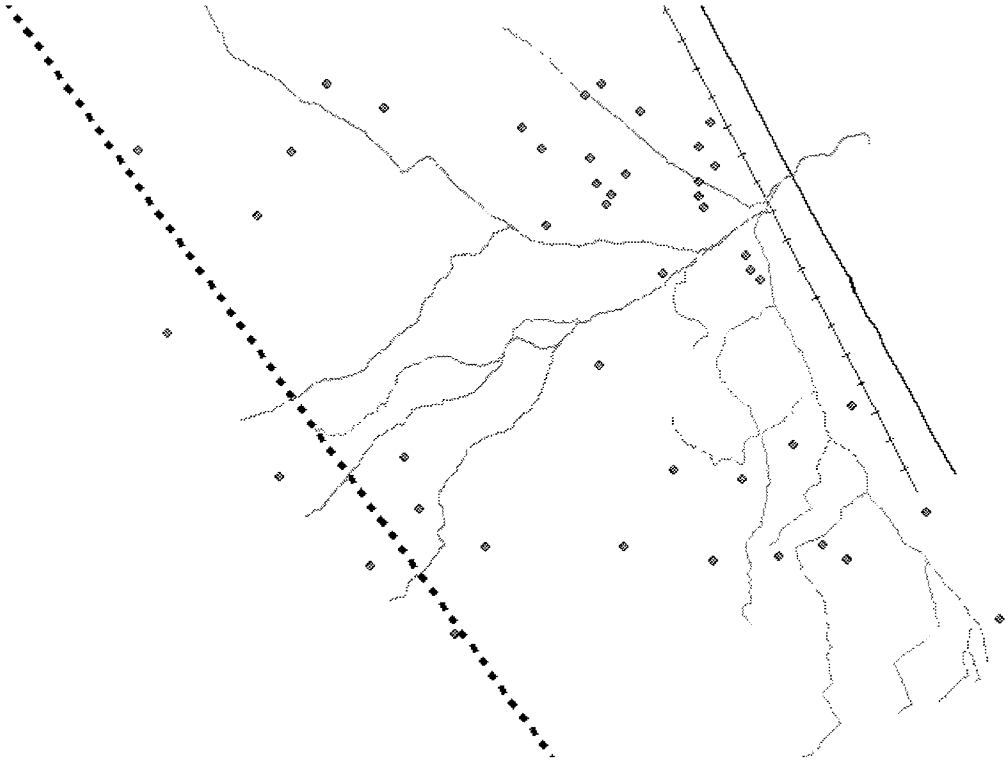


Figure 16. The dots illustrate the position of the fields that were analyzed in the study.

The number of interviewed farmers is approximately 6-7 % of the entire amount of peasants cultivating in this area. There is a high concentration of interviewed farmers in the northeastern section and a low concentration in the southwest section. This concentration could occur without a deterministic approach.

Soil management

Soil management refers to the use of agroforestry, subsoiling, manure, compost and fertilizer. The addition of these farming strategies gives each farmer a figure between 0-5 (in reality 0-3). A low number indicates poor farming practices. In Figure 17, this data is presented in a GIS-format and the values are interpolated with IDW.

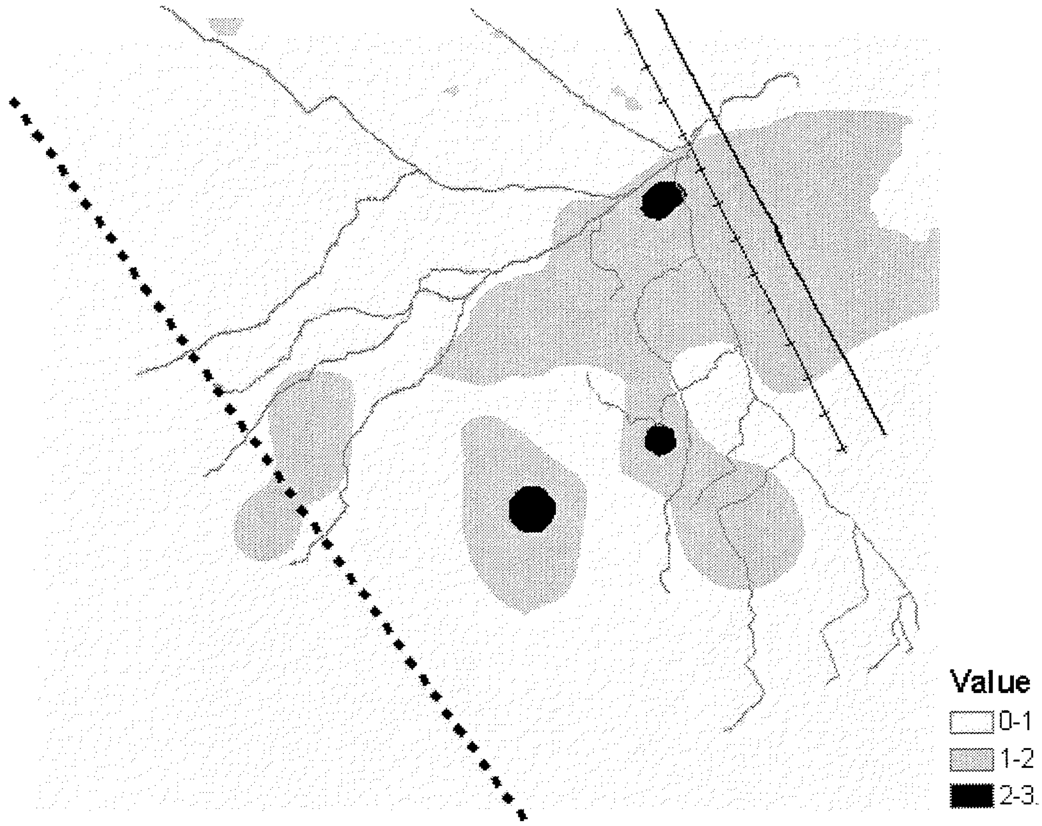


Figure 17. The input of soil management practices in Makanya. Areas with high input (more intense farming) are darker.

None of the farmers received more than a total of 3 points out of five. The black circle closest to the power line has a relative high value. This means that the farmers′ input of soil management techniques is rather high in this area. The correlation between the field and this area will be examined later (see a comparison of the maps below).

The soil management methods like agroforestry, subsoiling and inorganic fertilizer are not a common approach in Makanya. Agroforestry is only used in smaller fractions close the river outlet and further west on diminutive areas consisting of fruit trees mixed with maize or sorghum. During the field investigations, there were legible indications that the maize performed better under agroforestry conditions.

The use of inorganic fertilizer is not practiced in this lowland region, but several farmers use faeces from animals or manure. According to the questionnaire, approximately 20 % utilize excrements as a fertilizer for improving the soil condition.

Compost is a term for crop residues that are gathered and sometimes mixed with other organic matter for development of a nutrient rich material. This rich material could then be applied to the soil. The use of compost is relatively low, only 18 % of the farmers use this kind of application.

Water management

The basin sizes are important for the water management efficiency. The earth bund surrounds the field and defines the basin size. The basin sizes as a farming practice have been divided into three categories (none, small or large). Because of the gently sloping land, small basins are preferable concerning water losses. The basin sizes and the soil surface are important for a rapid and uniform distribution of water. A well-leveled soil has less deep percolation losses (FAO, 1971). The basins are both smaller and more frequently used close to the river outlet. The absence of a basin signifies the areas in the white section in Figure 18 below.

Earth bunds are used to prevent the water from leaving the field and instead infiltrate the soil. The utilization of earth bunds is a more common practice in the dark section and almost absent in the areas far from the river outlet. The earth bunds have been divided into three classes (no bunds, low bunds, high bunds). The picture below illustrates the use of earth bunds in Malaya.

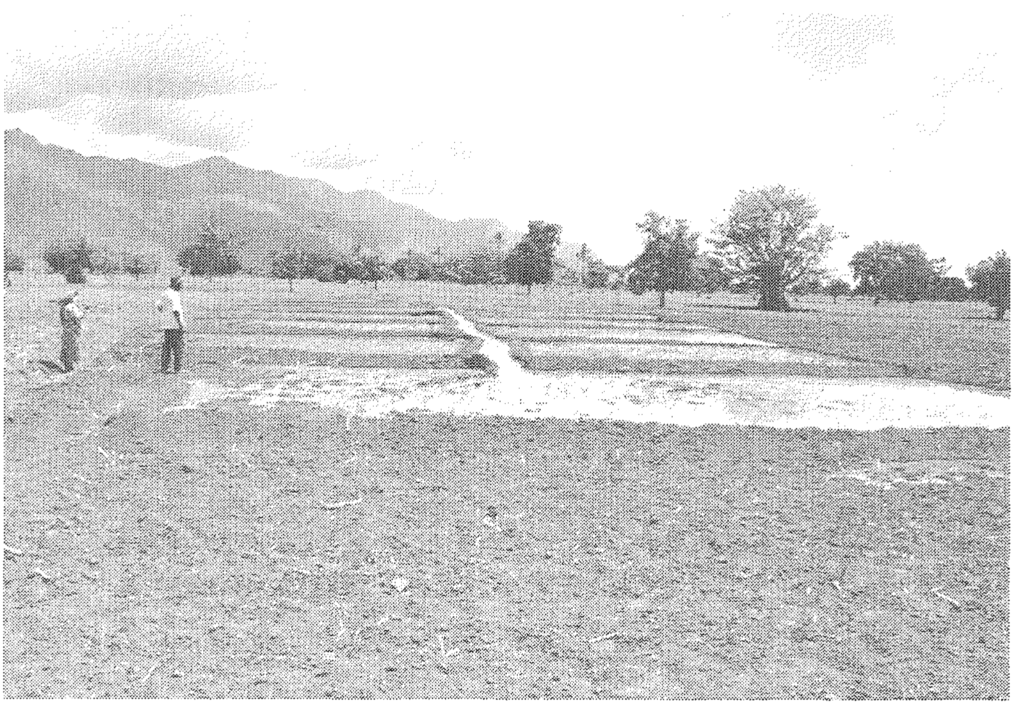


Figure 18. A photograph showing earth bunds to prevent the water from leaving the field. The water enters the basins from the river. Most of the farmers flood the whole field when the possible and try to saturate the soil (Photograph by the author, 2002).

Many farmers use bunds to prevent the water from leaving the field. The height of the bunds varies between 20-40 cm and approximately 45 % of the peasants employ earth bunds as a rainwater harvesting technique. Depending on the height of the bunds and the soil properties, the water lasts for different time periods on the soil surface. With sufficient bunds (25-30 cm) the water remains approximately one hour before it has fully infiltrated the soil.

The maintenance and the shape of the furrows or canals that transport the water to the field are of importance for the water´s velocity and its losses. A high water velocity affects the infiltration and evaporation rate negatively (Dupriez & De Leener, 1990). The shape of the furrows also influence the losses of water. Deep furrows with a small surface area lead to a reduction in the evaporation rate. Good furrows refer thus to the above criteria.

Deep planting is used by 4 % of the farmers according to the questionnaire. Deep planting pits refer to a system where the seeds are planted in deep (>30 cm) holes. Planting pits are created so the water is concentrated on a small surface area and used more efficiently. By constructing holes around the crop/tree, the water will remain there and infiltrate the soil where the roots are located and the requirements are high (see Figure 19).

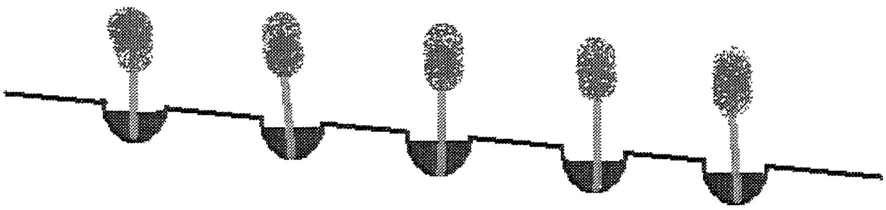


Figure 19. Deep planting pits to reduce runoff water losses.

Deep planting pits are used to accumulate the water where the crop is located. Figure 20 summarises the use of water management techniques in Makanya.

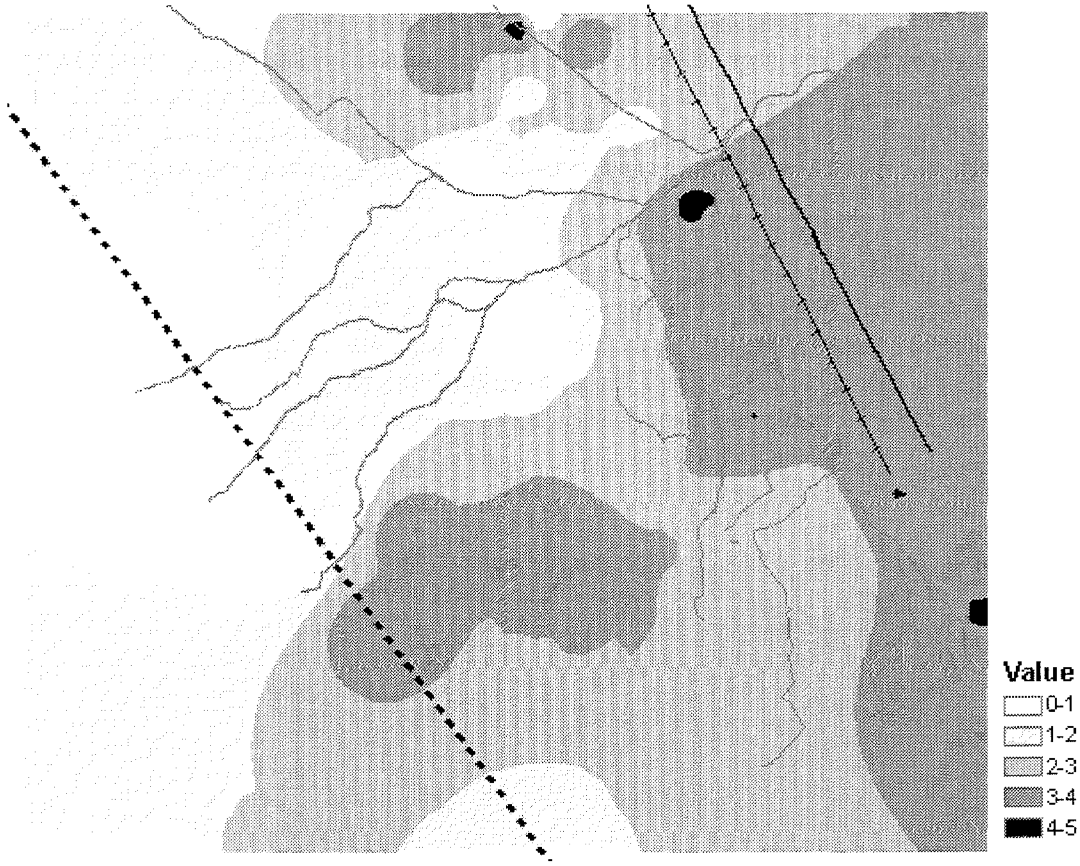


Figure 20. The input of water management practices in Makanya. Areas with high input (more intense farming) are darker.

The dark areas indicate good water management practices. A small dark grey area further from the river in the south part of the figure has a high degree of water management input, which coincides with the high farmer input area on Figure 17. This area will be examined further in relation to the yield and biomass production. Otherwise, the tendency is the same as above, a higher farmer input close to the river outlet and southwards.

Crop management

Under this section, five crop management techniques will be described and mapped (weeding events, use of pesticides, crop cover, crop rotation and windbreaks). Weeding simply means a removal of unwanted plants in the field. The number of weeding events are thus of importance for the plant growth potential. During the weeding event, the soil is also disturbed and the uppermost layer fractured. This will affect the infiltration rate positively. The numbers of weeding events vary in the examined area between different farmers. Some farmers stated that it is enough with 1-2 weeding events per growing season, but often the farmers weed 3 times per growing season.

The use of pesticides is a very common practice in the examined area. Pesticides (including herbicides and insecticides) are any substance or mixture of substances intended for: preventing, destroying, repelling, or mitigating any pest (EPA, 2003). Pests are living organisms that occur where they are not wanted or that cause damage to crops or humans or other animals. The use of pesticides is uniformly distributed in the cultivated area and a common practice. Over 85 % of the farmers employ pesticides.

Crop rotation is a frequently used method in the black and dark grey zone (see Figure 21). Totally, 22 % of the farmers utilize this technique. On the other hand, crop mixing is a much more uncommon practice. Only a few farmers claim that they mix crops. Crop-cover is not employed. Some farmers claim that crop-cover leads to more problems with insects and rodents. The variation between the farmers is immense. A high figure indicates good farming practice.

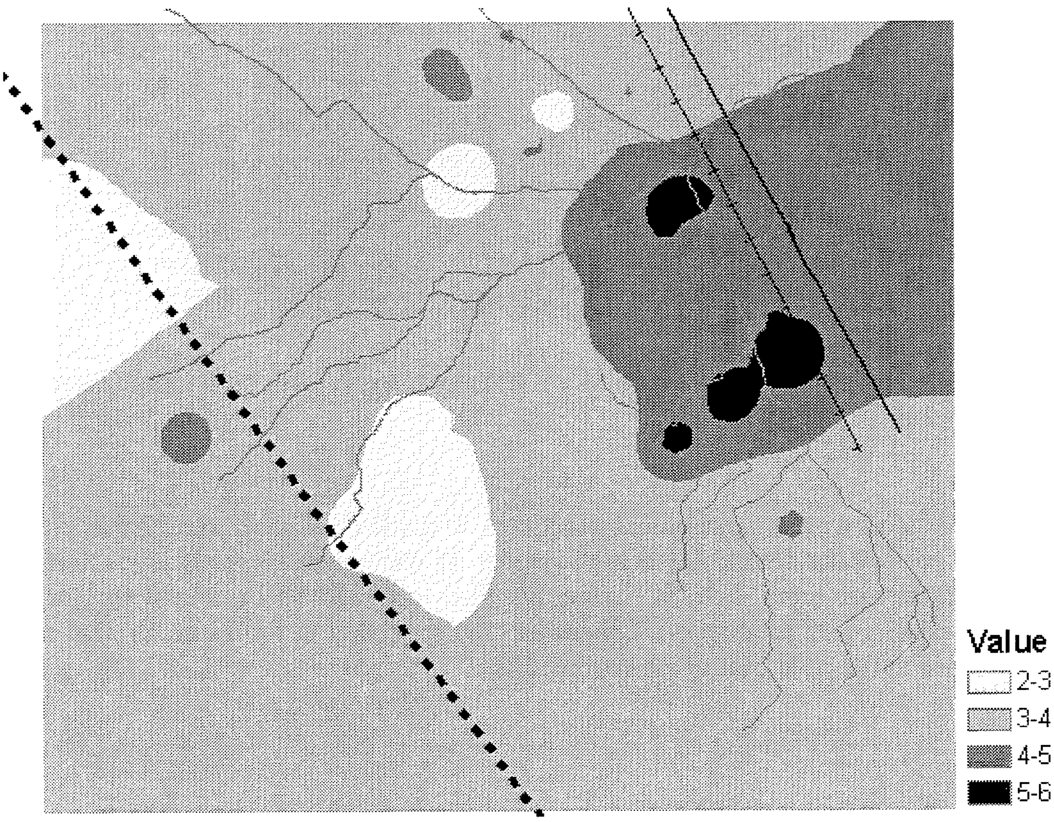


Figure 21. The input of crop management practices in Makanya. Areas with high input (more intense farming) are darker.

There is a more intense use of crop management strategies adjacent the river outlet. The concentration is evident in the section close to the road and railroad. Crop management practices are spread along the railway, southwards. The maps above illustrate the farmers′ input and the results show that there are more intense farming practices close to the river outlet. Some part of the light grey area, with a low farmer input, coincides with the high input areas in the Figures above (Figures 16 & 20).

Crop density

Crop density could be of importance for the growth potential. A high density could lead to competition between the plants and a reduction of biomass production. The crop densities are uniformly distributed in the cultivated area according to Figure 22.

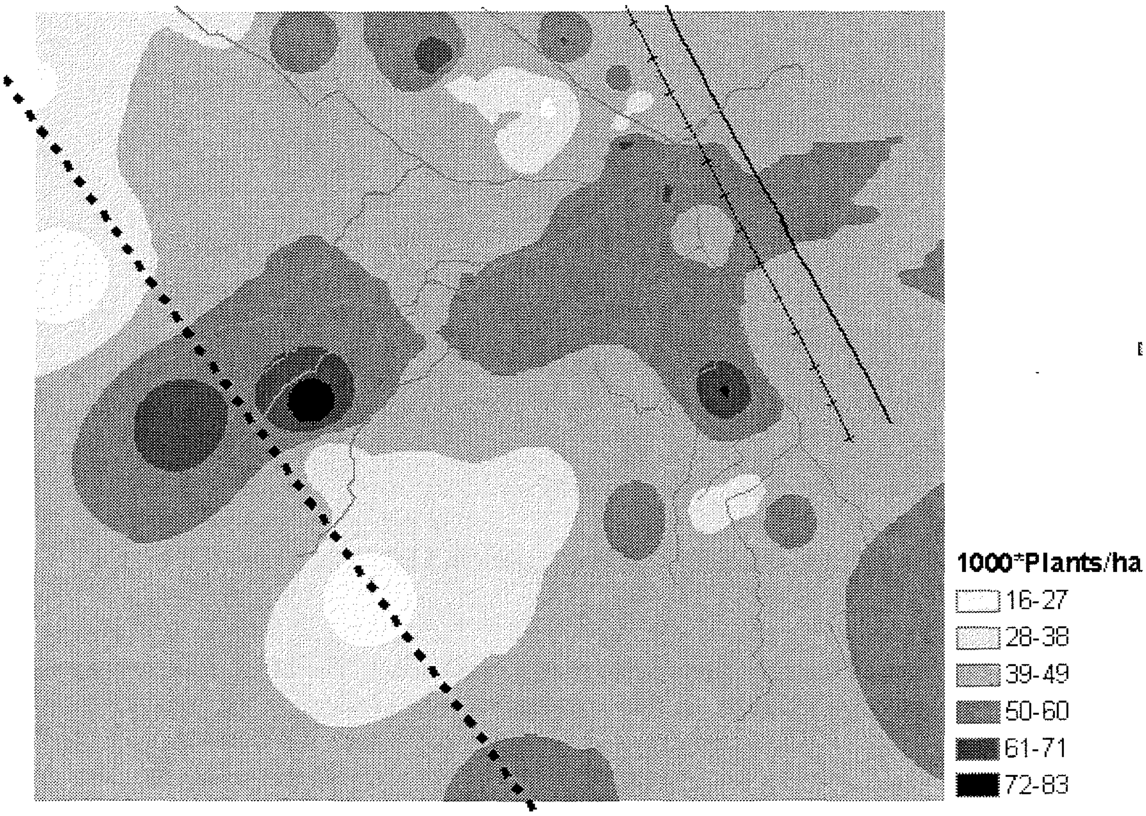


Figure 22. The plant density of maize in the cultivated area of Makanya.

There is no indication that this factor would influence the yields in a significant way.

The spatial distribution of average yield

The vast majority of the farmers in Makanya grow maize as a monoculture crop. This is one of the reasons why yields in correlation with the farming systems are comparable. The spatial distribution of the yields follows some patterns. The highest production is close to the river outlet, but also a few areas further down from the outlet have a relatively high production. In Figure 23, the yield data is illustrated spatially.

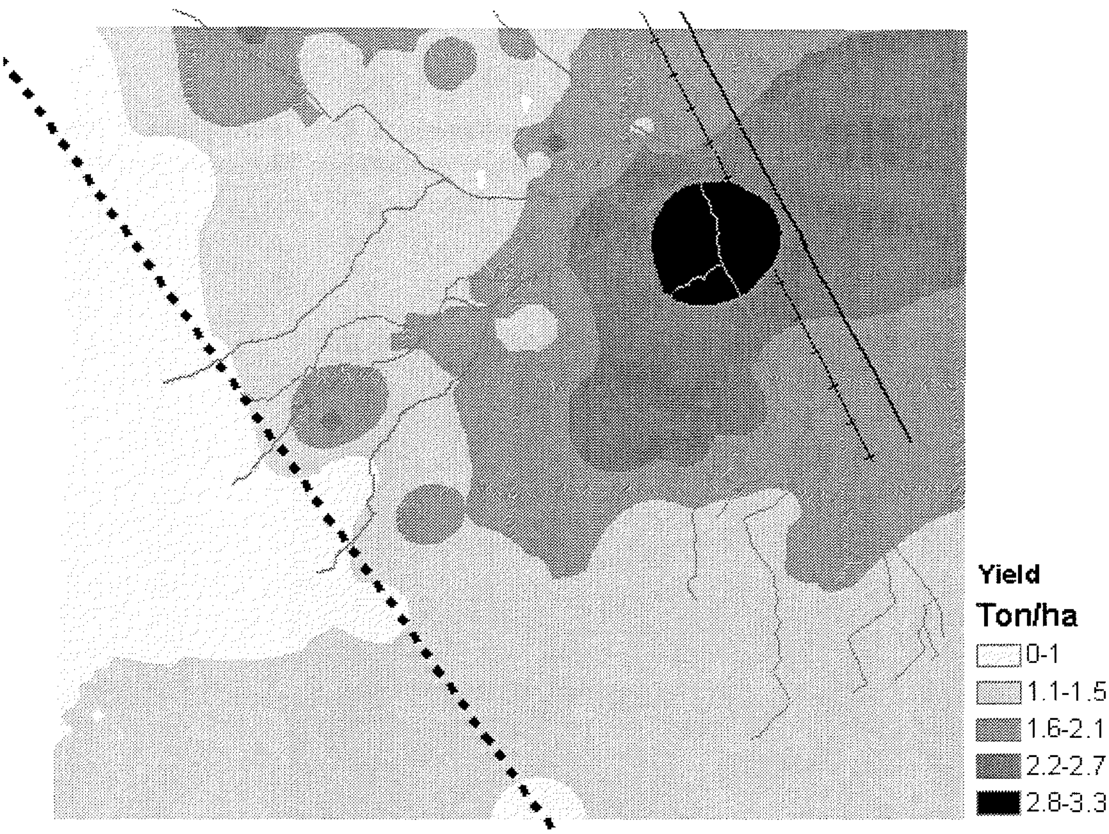


Figure 23. The spatial distribution of average yield of maize in Makanya.

To the right or the east side of the road there is no maize production. The black area represents a high concentration of yield or production. In this area the average production exceeds 2.8 tons/ha per growing season. The next section (dark grey) adjacent the black area has a lower productivity. The yield seldom exceeds 2.7 tons/ha and season. In the next section that surrounds the dark grey area, the yield is relative low, less than 2.1 tons/ha and season. In the light grey area that represents the majority of the color spectra, the production is less then 1.5 tons/ha. There is none or very little production in the area on the left side of the power line. The production is higher on the south side of the river outlet.

Average production of maize is three to four times higher in the black area close to the river outlet compared to the fields in the very light grey section. The water inflow is greater in the high production area close to the river outlet and because of the water usage/losses in this upstream area the farmers further below receive less water. As noted above, the production is higher on the south side of the river outlet and according to the field investigations, more water is discharged to this area. The slope from the outlet point to the position under the power line in the west is less than 2 %.

There is no indication that the production is significantly higher in the area with high farmer input of soil and water management techniques (Figures 16 & 20), but this will be analyzed below.

A comparison of the maps

It is difficult to observe the correlation between a specific farming practice and yield, but by adding different farming practices the result is obvious. There is a more intense farming close to the river outlet, a strategy that also dominates the south section of the river (see Figure 24).

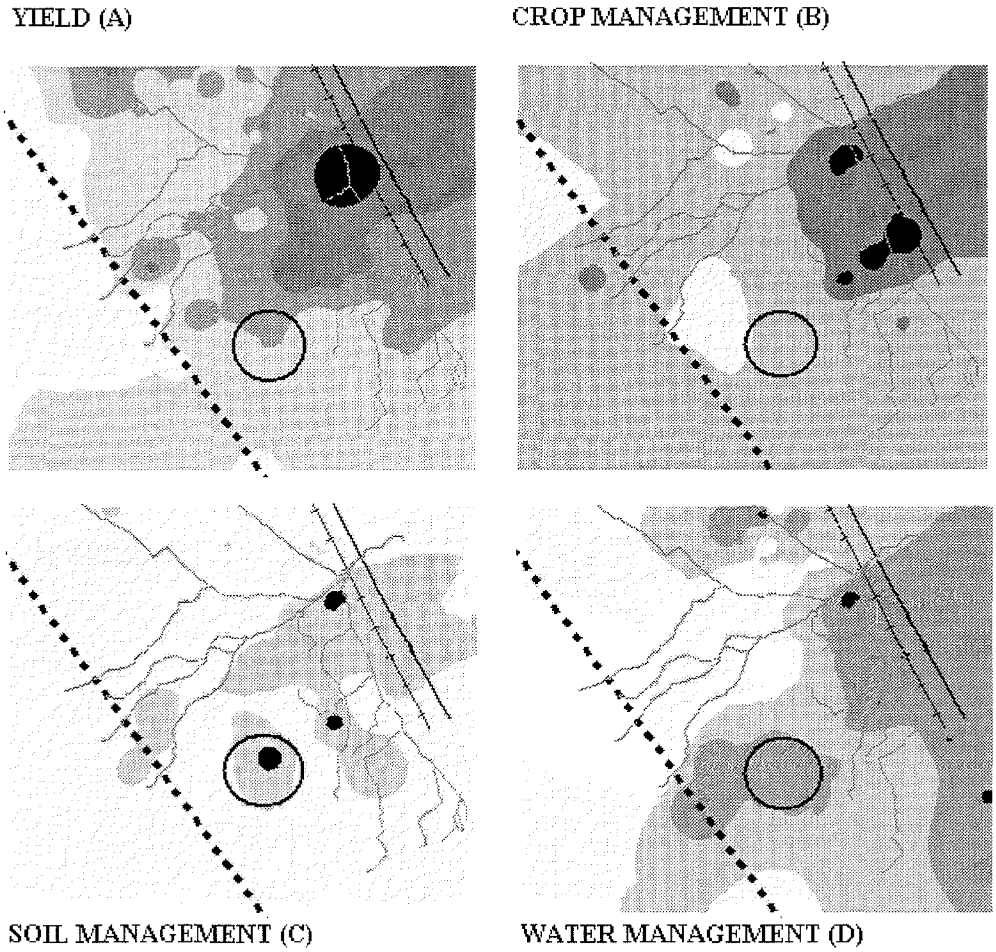


Figure 24. Shows the yield (map A), crop (map B), - soil (map C) and water management techniques (map D) used in Makanya.

Map (A) illustrates the spatial distribution of yield. The yield and the farmer input seem to be unrelated in general terms. A small area, marked by a black circle in the figure, has a relatively high input of both soil and water management techniques, but no increase in biomass production (see map A, B & C).

The dark color indicates high farmer input and there is a dark concentration immediately to the left of the canal outlet. The dark colors expand than more southwards. The section to the northeast of the river has a relatively low yield and low farming input. The result shows that farming is more intense where the water supply is higher.

Case study

The intention with the case study is to compare the crop production and the farming practices between two chosen farmers. The soil investigations are necessary to exclude other factors that could influence crop production. The GIS-maps are very general and thus the "case study" is of importance for the study.

The water supplies to the two farmers in the case study are similar due to the geographical position of the fields. Figure 25 illustrates the position of the current fields. The field of farmer (A) is much smaller compared to farmer (B) (around 1.2 hectares).

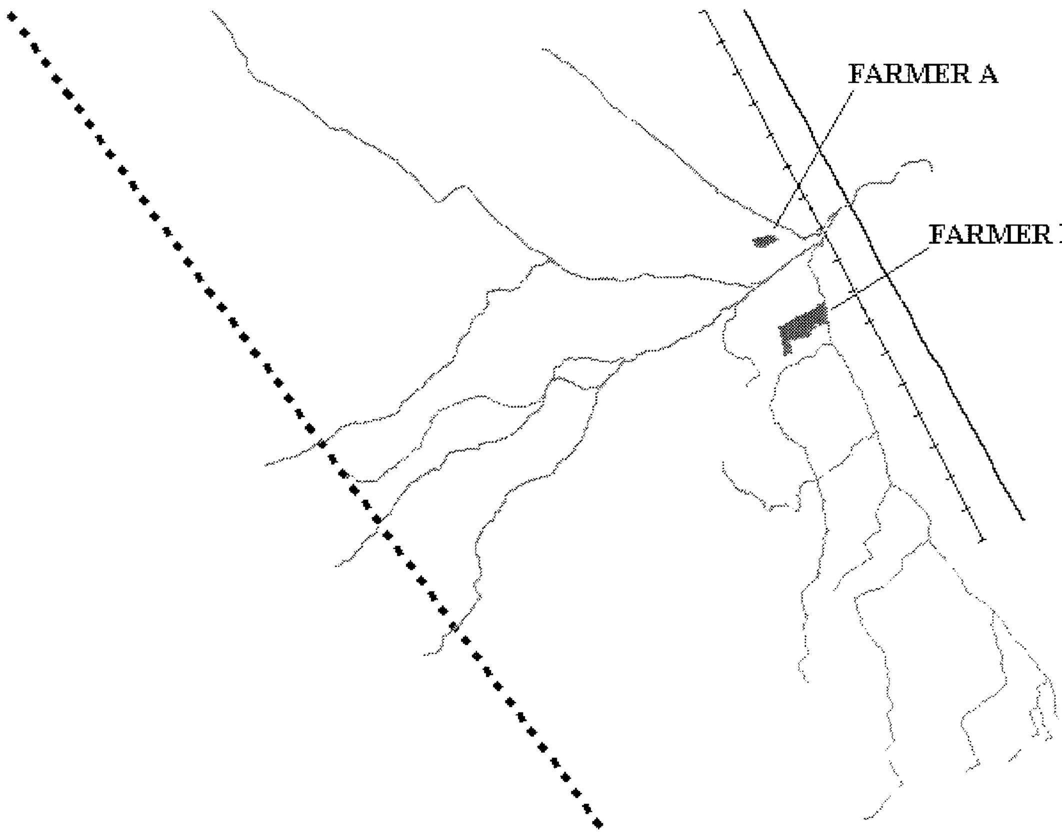


Figure 25. The river of Makanya with the two fields of farmer (A) and (B).

Yield and soil data

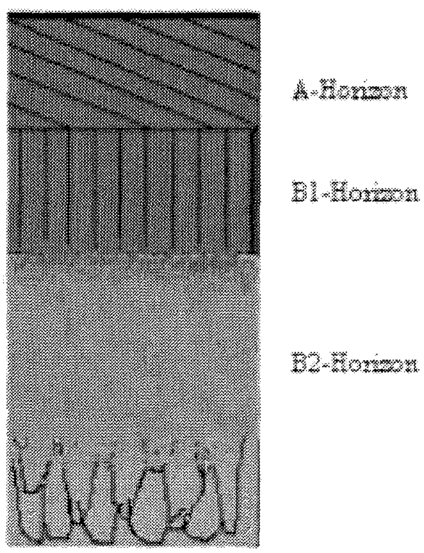
Below the results from the case study are presented in table form and discussed. Table 7 illustrates the crop characteristics and yield.

Table 7. Crop characteristic and yield of the fields of farmer A and B

Crop and yield	Farmer (A)	Farmer (B)
Main crop	Maize	Maize
Species	Local variety	Local variety
Average	6 bags/acre (1.2 ton/ha)	12 bags/acre (2.5 ton/ha)
Low	> 5 bags/acre (1 ton/ha)	> 5 bags/acre (1 ton/ha)
Occurrence of low yield	Seldom	Seldom
Maximum yield	10 bags/acre (2 ton/ha)	24 bags/acre (5 ton/ha)
Density of crop	36.000 plants/ha	65.000 plants/ha

According to Table 7 the average yield between these two farmers varies significantly. Farmer (B), located to the south of farmer (A), receives double the amount of maize per season. If the water is equally distributed than other factors must be of importance for the differences in biomass production (soil quality, fertility, farmer input, etc.).

Soil profiles
The soil profiles show the horizons and the status of the soil. The differences are minor, except for more evident horizons in the field of farmer (A). Summarized below is the soil of farmer (A) and (B) (see Figures 26 & 27).



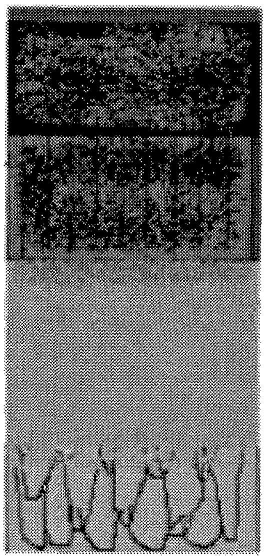
O-Horizon; not visible; very low amount of residues.

A-Horizon (0-20 cm); yellowish brown (YR10 5/4) alluvial sand mixed with clay (heavy clay); granular crumb structure; disturbed layer; very low organic content; low biological activity; high root density.

B1-Horizon (21-35 cm); Dark brown (10YR 4/2) clay mixed with sand (clay loam); granular structure; low organic content; low biological activity; root density moderate.

B2-Horizon (36-60 cm); brown (10YR 5/3) sandy texture; loose structure; no roots visible.
C-Horizon (61- cm); dark greyish brown (10YR 4/2) heavy clay; sub-angular blocky structure.

Figure 26. The soil profile of farmer (A).



O-Horizon (0-3 cm); intact and partially decomposed; litter layer composed of residues from previous season mixed with humus.

A-Horizon (4-22 cm); yellowish brown (YR10 5/4) sandy texture mixed with clay (light clay); granular to loose structure; high organic content; moderate biological activity; root density high.

B1-Horizon (23-40 cm); dark greyish brown (10YR 4/2) sandy texture mixed with clay; Sub-angular blocky structure; high organic content; low biological activity; root density moderate.

B2-Horizon (41-60 cm); brown (10YR 5/3) sandy texture; loose structure; low organic content; root density moderate; no roots visible.
C-Horizon (61- cm); dark brown (7.5YR 4/4) light clay; sub-angular blocky structure; low organic content; root density low.

Figure 27. The soil profile of farmer (B).

The structure of the examined soils differs slightly. At the depth of 60 cm and below the soil is more compact in the field of farmer (A). This characteristic could affect the root penetration to some extent, though the root system seldom exceeds 60 cm in this area. Normal root depth for maize is 1-1.5 m (Dupriez & De Leener, 1990), but according to the farmers and soil investigations this has not been established.

Farmer (B) has a higher organic content due to the input of residues, compost and manure and biological activity is also more intense. The texture in the C-horizon is clay for both horizons. The overall impression of these soils cannot solely explain the differences in biomass production. Table 8 below shows three macronutrients and the pH of the examined soils.

Table 8. Fertility status and pH* of the fields of farmer A and B

Nutrient & pH	Farmer (A)	Farmer (B)
pH	7-7.5	6.5-7
N (kg/ha)	58	64
P (kg(ha)	116	69
K (kg/ha)	130	145

* From soil investigations (2002-11-22 - 2002-12-12)

According to this data the soil fertility and soil structure are similar. The soil fertility of farmer (A) field is slightly higher, concerning the content of potassium and the phosphorus. The nitrogen content is a little higher in the field of farmer (B). The clay that dominates the field of farmer (A) could possibly explain the differences in soil fertility. The pH is also similar, farmer (A) has a higher value between 7 and 7.5. Table 9 summarises the soil characteristics.

Table 9. Soil characteristic* of the fields of farmer A and B

Characteristic	Farmer (A)	Farmer (B)
Fertility	Moderate to high	Moderate
Soil structure	Moderate	Good
Texture	Heavy clay	Light clay

*From soil investigations performed between 2002-10-18 - 2002-11-25.

According to the soil investigation the soils were comparable. The texture analysis indicates high clay content below the upper horizon on both fields. Alluvial material from the river is transported to the fields and the smaller fractions are transported effectively when the flow is low to moderate. These small particles (clay mainly) generate layers of a clay rich material.

Soil management

Below the soil management techniques employed are described (see Table 10).

Table 10. The input of soil management practices of farmer A and B

Management technique	Farmer (A)	Farmer (B)
Tillage	Hand-hoe	Hand-hoe
Agroforestry	No	Yes (little)
Manure	No	Yes
Inorganic fertilizer	No	No
Compost	No	Yes
Pesticides	Yes	Yes
Weeding	1-2 times	3-4 times
Windbreaks	No	Yes
Mixing crops	No	Yes

Both farmers employ hand-hoe as a tilling technique and use pesticides. Otherwise there are immense differences. Farmer (B) mixes crops (beans, sorghum) during some seasons to improve the soil structure. Trees and windbreaks to reduce the soil evaporation rate surround the farmer (B)´s field. Also, in some parts of the field, fruit trees are grown. The fruits can be harvested and the trees improve the organic matter of the soil.

Agroforestry has the potential of increasing the organic matter and the nitrogen content of soils. The growing of multipurpose tree species compatible with existing farming systems is important in soil management. Through agroforestry, trees provide nutrient inputs to crops by capturing nutrients from atmospheric deposition, biological nitrogen fixation, availability of nutrients from deep in the subsoil (deep nitrate capture) and storing them in the biomass (Sanchez, 2003).

Farmer (A) weeds 1-2 times per growing season whereas farmer B weeds 3-4 times, depending on the weed concentration. The weeding events are important for pest and disease control. To remove the unwanted plants is essential for the biomass production. The numbers of weeding events is thus of significance.

Farmer (B) uses manure and compost. These applications improve the fertility and the structure of the soil. These soil supplements increase the soil fertility and improve the soil structure (Weidow, 1998). Under the same moisture conditions in the soil, the crop-production increases with a good fertilizer management and is thus important for a sustainable production of food.

Pesticides consist of chemical components, are used to protect the crops from unwanted organisms (fungi, insects, etc.), and are used by both farmers in the case study. The application of pesticides could be done during seeding or the initial growth phase, but also during flowering and maturing.

Farmer (B) and not farmer (A) also utilize a crop mixing system (intercropping) in some seasons and on different plots. The mixing of crops will improve the organic matter of the soil and with perennial crops, the erosion rate will be reduced. In addition crop rotation can help to break insects, disease and weed cycles (USDA, 2003). Fogelfors (2001) claims that the yield can increase by 50 % compared to a monocropping system.

Water management

Table 11 illustrates the water management techniques used by the examined farmers.

Table 11. The input of water management practices of farmer A and B

Management technique	Farmer (A)	Farmer (B)
Small basins	No	Yes
Medium basins	No	-
Basic furrows	No	Yes
Marginal furrows	Yes	-
High bunds	No	Yes
Low bunds	No	-
Irrigation practice*	-	-

* The irrigation practices or the rainwater harvesting techniques are shown in Figure below

Figure 28 describes the irrigation practice and the water losses with a picture.

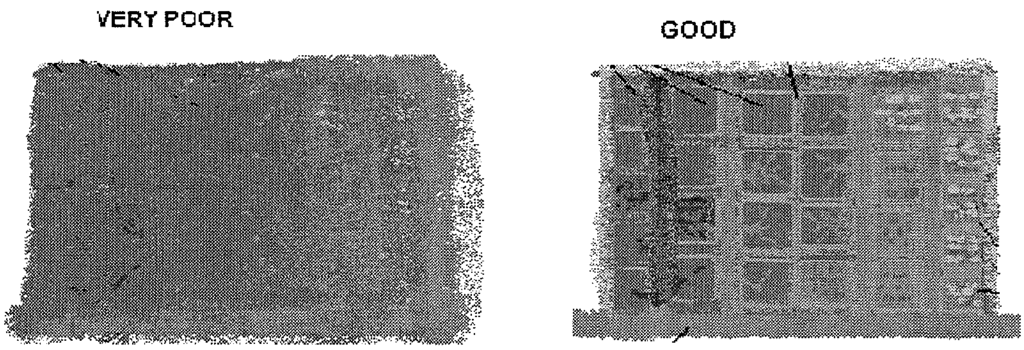


Figure 28. The figure to the left represents the field of farmer (A) and the figure to the right the field of farmer (B).

Farmer (B) put much more effort in water management techniques. When the water comes the grower has prepared the land adequately. Farmer (B) has small basins that affect the uniformity of the water flow. This is important for the infiltration rate and deep percolation water losses. The furrows that transport the water to the field and the earth bunds are well maintained in the right figure, but almost absent in the figure to the left. The water that enters the field in the left figure will rapidly leave the field as runoff.

All the above-discussed factors will affect the crop performance. The reasons why the differences are so significant most probably depend on the mismanagement of the water supply in combination with other poor farming practices. This data gives support to the statement that the yield could increase 2-3 times with judicious farming input if the water supply is acceptable and efficiently utilized.

Other farming practices in Makanya

Tilling techniques and seeding system

In Makanya the tillage technique is hand hoes and the farmers do not use animals as a source of power, which prevents the farmers from mixing the topsoil with the below horizons. Tillage aims to create a soil environment favorable to plant growth (Ofori, 2003). Definitions of tillage vary. According to *Soil and Agriculture* (2003), it is defined as physical, chemical or biological soil manipulation to optimize conditions for germination, seedling establishment and crop growth. Tillage operations loosen, granulate, crush or compact soil structure, changing soil properties such as bulk density, pore size distribution and composition of the soil atmosphere that affect plant growth. Appropriate tillage practices are those that avoid the degradation of soil properties but maintain crop yields as well as ecosystem stability (Greenland, 1981).

The tilling of the soil in Makanya is exhaustive. Before the rain starts in November and April, the soil is prepared by most farmers. This is a potential problem in some seasons because the seed starts to decay if the water is delayed. Another alternative is to wait for the rain and than seed, but than the risk increases that the farmer misses the opportunity of harvesting the first rainfall. The erratic distribution of rain is a major problem. In some *Mvuli* seasons, the rain starts to fall in the beginning of October and in other seasons at the end of November. With this arduous situation, it is very problematic to plan for the season.

The timeframe from seeding until harvest of maize is normally 90 days, with the variety they use in Makanya. This is the growth time under ideal soil, water and climate conditions. In Makanya, the peasants claim that it usually takes more than 120 days from seeding till harvest, depending on the water situation (Pers. comm., 2002). The maize can survive 3-4 weeks without water if the soil or the root zone is initially saturated (Berglund & Billvik, 2003).

The soil is tilled to a depth of less than 30 centimeters with little addition of organic matter. A few farmers only till the bare soil where the seeds are planted. This is problematic because of high runoff losses.

Irrigation practices in Makanya

Irrigation is a common practice worldwide. Approximately 20 % of the total cultivated land in the world is presently irrigated and by far the most common method is surface irrigation (Skogerboe & Wynn, 1987). The most utilized system in Makanya is a surface irrigation system. Surface irrigation "refers to a broad class of irrigation methods in which water is distributed over the field by overland flow" (FAO, 1992). Almost 95 percent of the irrigation systems used in the world is represented by surface irrigation and the technique is several thousands years old. The most common system uses an adjacent river or stream and guides the water into simple check dams connected to a canal. The water in the canal is than distributed to various locations where water is required (FAO, 1992). There are several types of SIS:

- Basin irrigation: Is mostly used on flat terrain, with level surfaces, and enclosed by dikes to prevent runoff. This system has complete perimeter dikes, and than basins are relatively small. Water is added to the field through a gap in the perimeter dike or adjacent ditch. With this system, it is very important to fill the basin quickly with water and shut off the flow when the right volume has been supplied. Moderate to slow intake soils and deep-rooted crops (Skogerboe & Walker, 1987) favors basin irrigation. There is, however, more limitations that are connected to this irrigation method. Appropriate land leveling and the maintenance of the perimeter dikes will greatly affect the application efficiency and this requires both knowledge and much labor input. Figure 29 illustrates a basin irrigation system.

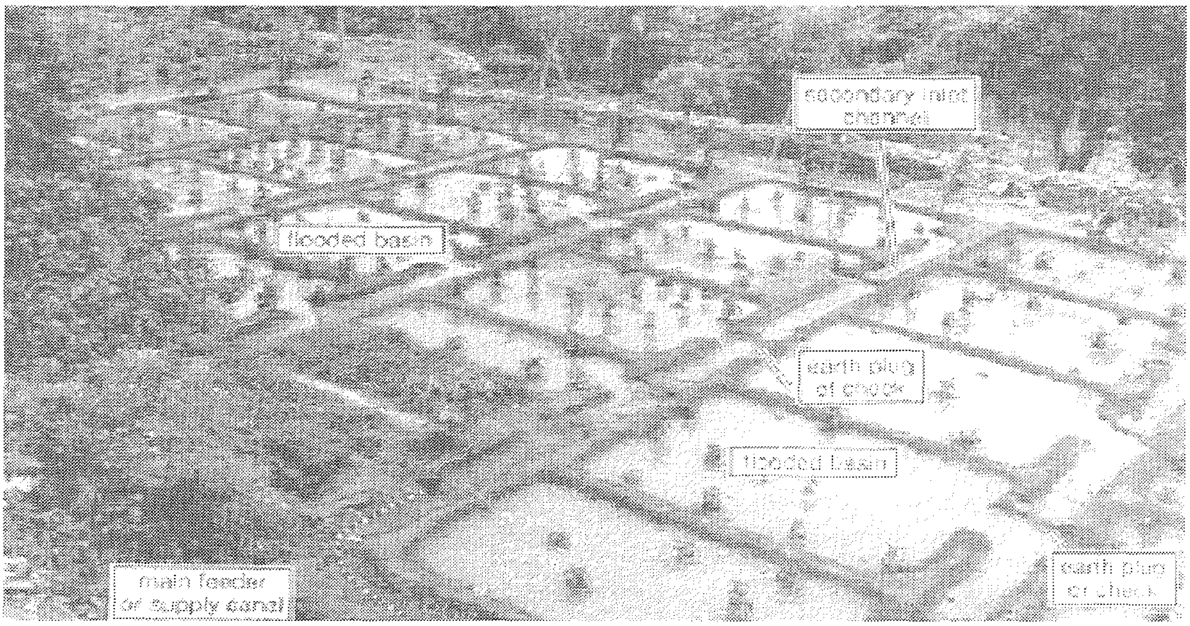


Figure 29. Illustrates a basin irrigation system (from Dupriez & De Leener, 1990).

- Border irrigation: Is similar to basin irrigation, but the size and the shape of the basin generally differ.
- Furrow irrigation: Instead of flooding the whole field, an alternative is constructing small channels along the primary direction of water movement. The water in these channels will infiltrate the wetted perimeter and move horizontally and sometimes vertically to refill the soil.

The common practice in Makanya is basin irrigation. The system is also called ephemeral stream diversion (FAO, 1992). When a basin is full, the inflow canal is closed and the water continues to flow to the next basin. The maintenance of the basins and the furrows are therefore of vital importance for adequate crop production.

Figure 30. The irrigation practice employed in Makanya. The water is lead into the furrows and then distributed to the fields. The earth bunds and basins are also visible. (Photograph by the author, 2002)

Rainwater harvesting

The irrigation techniques used in Makanya could be considered as a rainwater harvesting system (RWH). The river receives rainwater from the watershed in the mountains and the farmers then utilize this runoff water. RWH simply means the collection of water during the rainy season to meet the water needs in the following dry period (Hatibu & Mahoo, 2000).

There are different kinds of RWH and two of them are utilized in Makanya and classified as in-situ and a micro-catchment RWH system. In-situ RWH is also known as soil-water conservation techniques. This means that the rain is conserved where it falls, but no additional runoff is introduced from elsewhere. The aim is to increase infiltration and decrease runoff. This can be done with, for example, deep tillage, which means to disturb the soil surface structure in order to increase or create a rough soil surface (Mzirai et al, 2002).

Micro-catchment (MC) means collection of runoff water from a large external source, upstream from the harvesting area point of view. Example of techniques, using MC, is diversion from rangelands and roads. This water is then used immediately without storage structures (in-field farming) (Mzirai et al, 2002). In Makanya, the utilization of RWH techniques is high, but the people still face extreme water shortages regularly. Some of the livestock keepers use excavated earth dams to harvest sheet runoff water. These dams are connected to handmade canals that transport the water to the dam location. This water is, however, not enough for a systematic crop-production, but instead used for livestock, domestic and home-gardens. This indicates that the inhabitants of Makanya employ the water efficiently and that knowledge about RWH among the farmers is relatively high. The potential of RWH depends strongly on the rainfall type (intensity and duration).

The quantity of runoff water from the Pare Mountain watershed depends on several factors: such as, the usage and losses of water in the upstream areas, the rainfall intensity and duration. Because of the specific situation in Makanya, where the seasonal rainfall is below the minimum seasonal plant water requirement, the water from the mountains is necessary for production of crops. Therefore the *type* of precipitation in the highland of vital importance for the farmers of Makanya. A high intensity rain will generate runoff that could be harvested by the farmers in the lowland areas. With a high intensity rain with few events and a low amount, it is thus possible to produce some crops. Other regions were none or low input of RWH-systems is used, the distribution and amount of water is more essential for food production.

Crop production and field plots in Makanya

Maize (Zea mays L.) is, as noted above, the main crop in Makanya and during *Mvuli* the vast majority of the farmers cultivate only this crop. In the *Masika* season a few farmers mix crops (beans, lab-lab, sorghum, maize), but this is not a common approach. Mixing crops or intercropping could affect the biomass production positively (Fogelfors, 2001). The system of crop rotation (different crops per season) is not widely employed in Makanya. Maize could, however, be cultivated on the same field each season without a significant decrease in production (Weidow, 1998).

There are approximately 600-700 farmers (A. Msangi, pers. comm. 2002) that cultivate an area of around 400-450 hectares in Makanya and the average size of the individual field varies between 0.5-3 acres (0.2-1 ha) (Pers. comm., 2002). However, many farmers own small plots of land or fields widely distributed in the agriculture area. One farmer could own three hectares of land, land that is scattered over a large area. This is partly a result of the land inheritance system, where the parents subdivide the land among the children, but also a farmer strategy for risk distribution. Farmers, therefore prefer to have plots located in different geographical areas (Mzirae et al, 2002). The average yield of maize for the completely cultivated area fluctuates between 0.6-1.3 (~1.0) tons per hectare depending on the season.

5. DISCUSSION

The results from the GIS-analyses in Makanya indicate that the yields of maize do not increase notably with a high farmer input because of the water shortages. The water supply controls the crop performance and the water is normally efficiently utilized in Makanya. A common approach is rainwater harvesting (RWH) and in general, terms lead RWH to a yield improvement. A recent report from Same district shows that the yields of maize and paddy rice increased significantly with different RWM systems (Mzirai et al, 2002). Field studies in Burkina Faso and Kenya show the possibility of doubling or even tripling the yield using RWM (Fox & Rockström, 2000). In a long-term study performed in Mwanga district only 60-80 km north of Makanya shows that different kinds of RWH techniques does not significantly increase the yields in the Masika season. There is, however, a legible increment in Mvuli season with the employment of a microcatchment RWH-system (Hatibu et al., 2001). Yet these results are difficult to apply to Makanya conditions because of differences in slope, altitude and yearly precipitation. There are also some indications, from earlier research in the area, that the water management techniques or the available runoff resource is already exploited to its capacity (Mzirai et al., 2002).

Hudson (1995) and Mzirai and co authors (2002) claim that the introduction of other farming methods or strategies like manure, pesticides, chemical fertilizer and systematic weeding could double the yields. The data from Makanya does not support this statement. The "case study" however illustrates how different farming practices could affect the biomass production significantly if the water is sufficient. When discussing the introduction of farming practices it is thus necessary to consider the water situation.

To improve the water situation and the yields in Makanya more research are required. The discussion below is concerned with this topic. The water shortages in Makanya are due to several factors. One is the rainfall distribution and amount, but also the river flow. The Makanya River and other streams from the highlands are drying up due to poor catchment management. Increased cultivation and water utilization in the highlands has led to decreased runoff to the lowlands (SWMRG, 1999). A more efficient use of the water source in the highlands could improve the situation in the lowland areas. To bridge longer dry spells it is necessary to construct storage structures for RWH or distribute water from other adjacent areas (or use of the groundwater). Improvement of the in-situ RWH systems could be done to some extent. Also a reduction of the field sizes. The low fertility fields can be abandoned and the work labour could focus on the fertile soils. This will reduce the water demands and losses and possibly also increase yields.

By planting more trees or mixing trees with crops, the situation could improve. According to Evans and co authors (2000) the transfer of biomass from one site to another could also provide nutrient inputs. These nutrients become available when the biomass is decomposed in the soil. Trees can also enhance nutrient cycling through conversion of soil organic matter into available nutrients (especially N and P). It is, therefore, possible to recycle nutrients through litter-fall, root decay, and green manure. Agroforestry also benefit farmers directly through the provision of poles for building, fruits for sale and consumption, fuel wood, and fodder for livestock. The trees also prevent soil erosion, conserve soil moisture; improve soil fertility and the microclimate. The environmental benefits of trees include soil conservation, bio-diversity conservation, and conservation of terrestrial carbon.

There are different kinds of tillage systems and a popular trend is conservation tillage. According to the *Conservation Technology Information Center* in Indiana, USA, conservation tillage is defined as "any tillage or planting system in which at least 30% of the soil surface is covered by plant residue after planting to reduce erosion by water" (Evans et al., 2000). According to Evans and co authors (2000) a no-tilling system is advisable, but then it is necessary to leave the crop residues unaffected. The crop residues are generally removed from the fields in Makanya and conservation tillage is thus not practiced.

Antap and Angen (1990) claims that the no-till system of cultivation forms a basis for conservation farming because it conserves water, prevents erosion, maintains organic matter content at a high level, and sustains economic productivity. Antap and Angen (1990) also report that retaining crop residues on the soil surface with conservation tillage reduces evapotranspiration, increases infiltration rates, and suppresses weed growth. More research is, however, required to examine the potential of this practice in Makanya.

It is also important with appropriate recommendations to the farmers. The advices should be based on scientific data from well-designed and adequately equipped long-term experiments. The priorities for the development of conservation tillage systems include: (i) the development of cheap alternative methods of weed control; (ii) the development of effective and specific herbicides to control weeds (such herbicides should not harm subsequent crops); (iii) the development of suitable crop rotations including cover crops, and improved cropping sequences that result in more effective storage of rainfall and efficient utilization of soil available water, (iv) provision of appropriate equipment for planting and fertilizer application, and (v) the breeding of crop cultivars that are adaptable to conservation tillage systems and also have characteristics that aid in erosion control as well as improve soil fertility.

There are, however, many problems concerning the implementation of "new" technologies. A major constraint is the farmer knowledge and/or lack of resources (Mzirai et.al, 2002), but other factors are also important.

Conclusion

This study has examined the spatial distribution of farming practices and yields of maize (*Zea mays L.*) in Makanya village, Tanzania in order to discuss if an improved farming strategy could improve the yields significantly. The basis for the discussion is the geographical information system (GIS) analyses and the "case study".

The farmers of Makanya cultivate a large homogenous area (400-450 ha) and the average size of the individual (family) fields varies between 0.3-2 hectares. Different farmers employ different farming methods to produce crops (maize), which made it interesting to study the data spatially. The result from the GIS-data indicates that the farmers invest more resources in areas where the water situation is enhanced. The water affects the farmers risk perceptions and thus reduces incentives to invest in improved management in areas where water is insufficient. The GIS-maps also show locations where the farmer input is relatively high, but biomass production is not clearly affected. The GIS-maps could thus not support the general statements that a high farmer input increases the yields mechanically. This is due to the water constraints in Makanya. The "case study", however, illustrates how an intense farming system could double or even triple the yields if the water is sufficient or if the water supply is acceptable.

The production of maize could increase significantly in Makanya on a small geographical area close to the river outlet with a more intense farming system. This area could provide food to a few farmers and families in Makanya, but the majority of the farmers, further down the river, still face serious problems. To improve the water situation in Makanya more efforts should be addressed the water management in the highlands.

This thesis had tried to investigate the correlation between farming practices and yield. As, the study based on small sample and on a very short timeframe, much more studies are required in this field of research.

Sources of error

This study is mainly based on social information, which could be problematic. First, the farmers had to estimate the yield, which could be a source of error. Earlier research in the region has, however, presented similar data in average values. To perform this study more systematically much more time is required. Other social data like the use of farming practices could also be inaccurate because the informant are affected by the situation.

In the GIS-analyses, the social, technical and direct observation data were translated into figures or values, which could affect the results. A high value does not always correlate to the real situation. This also means that the amount or the extent of each management techniques was not investigated. The direct observation could be affected by "timing". This means that the farmer had not prepared the field thoroughly under the interview occasion, though I went out several times during the growing season so hopefully this source of error is limited. Random selection is always a problem because of the representatively. There is a chance that the farmers that were interviewed belong to a certain category.

Finally, the fertility and the texture analysis. The texture was analyzed with a simple test that could be inaccurate and the fertility analyses were not performed under laboratory conditions.

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APPENDICES

APPENDIX 1

Questionnarie

Questionnaire: Agriculture questions
Water balance accounting for planning of rainwater harvesting in Makanya, Tanzania
Sofia and Peter, October 2002

General information

Name:
Date of questionnaire:
Members of the family supported by you:
Location; Sub-village of farmer: Date of birth:
Location of field:
For how many generations have the family owned the field:
Most important farming activity for income (ranking: 1-high; 5-low): a) Food crop_____________ b) Cash crop_____________ c) Live-stock_____________ d) Others____

To River-farmers mainly:

Flow under road bridge: yes_________no__________
If no: how many meters below road:_____________
How many farmers uses the river as a water source for their fields:__________
The total area of the fields supported by the river:_____________
When does the Vuli rain season start and end:
Start_________________Ends___________________
When does the Masika rain season starts and end:
Start_________________Ends___________________
The name of the period between the season:__________________
The rain amount in this season:__________________
How many times per season does the river contain water:
Vuli_______________Masika________________
How much flow of water in average (height) per season:
Vuli__________Masika____________
For how long time does the river contain water during these times in average/season:
Vuli_______________Masika________________
When was the river flooded the last time (date or month and year)______________________
Do you remember a specific year when the river was extremely flooded:
(yr)__________(season)____________

How many times during **Masika season 2002** did the river contain water____________
For how long time each time: First________Second_______Third_________Fourth______
The height per time: First________Second_______Third_________Fourth_____
Average = peak flow/2
How many times during **Vuli season 2001-2002** did the river contain water____________
For how long time each time: First________Second_______Third_________Fourth______
The height per time (average): First________Second_______Third_________Fourth_____
How many times during **Masika season 2001** did the river contain water____________
For how long time each time: First________Second_______Third_________Fourth______
The height per time (average): First________Second_______Third_________Fourth_____
How many times during **Vuli season 2000-2001** did the river contain water____________
For how long time each time: First________Second_______Third_________Fourth______
The height per time (average): First________Second_______Third_________Fourth____
How long time of rain before river start containing water: ________________
Speed of water in the river:____________________
How much water is distributed to your field of 100 percent:___________

Soil classification and water runoff/run-on

What soil type do you have (local name & Kiswahili name) Catchment area: In fields: Field I: Field II: Field III: Field IV:
Fertility and area per field: Field I: High_________Moderate___________Low______Size_________ Field II: High_________Moderate___________Low______Size_________ Field III: High_________Moderate___________Low______Size_________ Field IV: High_________Moderate___________Low______Size_________
Root depth: Deep (> 90 cm) Moderate (60~90 cm) Shallow (< 60 cm)
Problems working with the soil:
Is your field bunded: yes______________no_____________ if yes: the height of the bunds:_______________ Is the field waterlogged during the growing season Field I: Masika: yes_____no______Vuli: yes____________no___________ Field II: Masika: yes_____no______Vuli: yes____________no___________ Field III: Masika: yes_____no______Vuli: yes____________no___________ Was it waterlogged the last season/Masika (2002): yes________no___________ For how many times is the field/s waterlogged in average per season: Vuli_______________Masika_______________ For how long time is the field waterlogged per time: Vuli_______________Masika_______________
Different layers in the soil that is a problem for agriculture purposes and why (clay layers, murram, rock, depth, others):

Crops/weeds

Different kind of crops:______________________________
Density of crop (Maize):___________________________
Main crop per season:
Vuli____________________________Masika____

Yield with main crops in average per season:
Vuli:____________________________Masika__________________________
How much a is a very low yield/acre: 1 bag_____2 bag______3 bag_____4bag____
______5bag_____6 bag_____7 bag______8 bag______9 bag
How often do you have average yield (________):________________
How often is the yield very low (____________) or none:
How often is the yield very low
1/10 year____2/10____3/10____4/10_____5/10______6/10____7/10_____8/10_____9/10_____
How much is a high yield:_____________
When did you last time had a high yield:__________
Maize yield 2002 (Masika): High_______Moderate_________Low_______Bags______
Maize yield 2001-2002 (Vuli): High_______Moderate_________Low_____Bags______
Maize yield 2001 (Masika): High_________Moderate_________Low_____Bags_____
Maize yield 2000-2001 (Vuli): High________Moderate_____Low_______Bags_____

Crop season (starting point for different crops & harvesting):
Maize (month): Vuli
Seeding__________________________Harvest______________________
Maize (month): Masika
Seeding__________________________Harvest______________________
Beans (month): Seeding__________________________Harvest___________________
Others:______________________________
Do you seed before or after the rains starts: before_______________after_______________
When did you sow year 2001 (long rain & short rain) and 2002 (long rain)
2002 2001
Masika____________________________
Vuli_____XXXXXX________________

Dry spells within the growing season:
Vuli_______________________Masika_________________
How long: Vuli_______________Masika________________

Water shortage - in what stage of the growing season does normally the Maize suffer from water deficit (normally):
Vuli Masika
Germination________________________
Vegetative__________________________
Flowering__________________________
Maturing__________________________

In which growth stages are maize most sensitive to water deficit?

Germination:_______________ Vegetative________________ Flowering_________________ Maturing_______________
Mixing crops: yes_______________no_______________ Which crops: For how long time:_______________
Limitation to cropping: yes____________no____________ if yes indicate the limitations:
Size of agriculture field (acre):
Is there weeds in the field during *Masika*: High_____Moderate______Low_____none_____ Is there weeds in the field during *Vuli:* High___Moderate_____Low______None_______
When do you weed in Vuli season (Maize): weeding 1:___________ weeding 2:___________weeding 3:___________ When do you weed in Masika season (Maize): weeding 1: weeding 2: weeding 3:

Rain distribution
Jan: Much__________Moderate______________Low__________None__________
Feb: Much__________Moderate______________Low__________None__________
Mar: Much__________Moderate______________Low__________None__________
Apr: Much__________Moderate______________Low__________None__________
May: Much__________Moderate______________Low__________None__________
Jun: Much__________Moderate______________Low__________None__________
Jul: Much__________Moderate______________Low__________None__________
Aug: Much__________Moderate______________Low__________None__________
Sept: Much__________Moderate______________Low__________None__________
Oct: Much__________Moderate______________Low__________None__________
Nov: Much__________Moderate______________Low__________None__________
Dec: Much__________Moderate______________Low__________None__________

Rain intensity (high, moderate, low) in the raining seasons:
Masika: Very high__________High_______Moderate___________Low___________
Vuli: Very high_________High___________Moderate___________Low___________
Kipupwe: high________moderate________low_________
How often does surface runoff water occur (footpaths, roads, etc):
Masika_______________Vuli__________
For how long time of rain to create runoff:
5min_____10min_____30min______60min______120min______4h_____
10h_____20h______
Temperatures:
hottest months_________________________________

coldest months____________________________________
Wind over the year:
Windy months______________________Time__________________
not windy months_________________________________
RWH-system used:
For how many years have you used RWH-system:____________
Why not before?__________________________________
Canals: yes________________no_________________
Bunded area: yes_______________no_______________

Management:
What kind of tillage system do you use:
Deep tilling (> 1 feet): yes________no________
Constructing holes around the plant for increased infiltration: yes_____no______
Compost: yes________no_________
Inorganic fertiliser: yes_______no_________
Manure: yes_________no__________
Pesticides: yes_______no________
Intercropping:yes____no______
Ground cover: yes_____no_____

Name of farmer:______________________________
Location of field:______________________________

Technical investigations of field

Measurements	**Method**	**Result**		
		Field I	Field II	Field III
Texture of the soil (top soil):	Rolling test			
Sample I				
Sample II				
Sample III				
Bunded height:	Measurement tape			
Slope:	GPS			
Crop density:	Measurement tape			
For only two fields				
Root depth:	Profile analysis			
Layers:	Profile analysis			
Deep tillage:	Profile analysis			
Infiltration capacity:	Bottle plus water			

Visual investigations of field

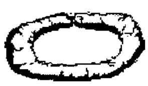
Soil roughness: Little___________Moderate___________Much___________
Soil crust: Little____________Moderate_____________Much__________
Soil structure: Blocky________Granular or crumb________Loose (single grained)___________
Water conservation tillage: yes___________no___________
Big planting holes (Vitengo): yes______________no__________
System I______________________________________: yes___________no___________
System II______________________________________: yes___________no___________
System III_____________________________________: yes___________no___________
Agroforestry: yes_____no____
Windbreaks: yes______no____

APPENDIX 2.

Soil texture analysis method

The soil texture describes the grain size of the soil. The particles are sand, silt and clay, where sand is the largest grain size, silt is medium and clay is the smallest. Loams are soils of mixed grain sizes. The texture of the soil plays a major roll for e.g. infiltration rate and agricultural purposes. The rolling test is used for differentiation between clay, silt and sand soils.

1. Take a handful of soil
2. Slowly add little amounts of water and mix it very well with the soil sample. Stop adding water when the soil ball gets sticky in your hand.
3. Try to form the soil sample into the different shapes demonstrated below. See how many of the pictures you can form with the soil. Stop when no more figures can be formed.
4. Read the soil texture for the last figure you can shape. This is the texture of your soil.

The soil remains loose and single grained and can not be formed to anything but a pyramid:		Sand
The soil can be shaped into a ball:		Loamy sand
The soil can be formed in to a short, thick cylinder:		Silt loam
The soil can be rolled into a cylinder of about 15 cm length:		Loam
The soil can be bent into a U:		Clay loam
The soil can be bent into a circle, but with cracks:		Light clay
The soil can be bent into a circle without cracks:		Heavy clay

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