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Water Management and Smallholder Fairtrade Tea Producers in South Western Uganda

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Abstract

Kayonza growers' tea factory is a remote tea factory in south western Uganda which consists of two core estates and 4072 smallholder tea farmers currently producing tea over a total area of 1604 hectares. There is a perception that yields of smallholder tea vary significantly throughout the year and between years. The data confirms this, with yields in the lowest producing months of February, July and August as little as 6% of annual yield production. Soil type also has an influence on yield with evidence suggesting that sandy loam soils suffer from more drought days than clay loam soils and generally have more uneven yields.

The conceptual framework for analysis included a water balance model and a sustainable livelihoods framework. Methods of analysis included yield modelling, climate analysis and construction of a soil water balance model. Semi-structured in depth interviews with stakeholders formed the basis of sociological data collection. Soil water deficit modelling showed seasonal water deficits and a prolonged water deficit in 1999. Total available water was calculated to be 84 mm for clay loam soils and 42 mm for sandy loam soils. Yield analysis showed average yields of made tea to be 1250 kg ha^{-1} in 2005. However, yield prediction estimated possible yields of 2378 kg ha^{-1} of made tea. Yield patterns followed soil water deficits and correlated with rainfall patterns. Yield evenness may be affected by soil type differences in the Kayonza Growers Tea Factory area. Interviews with stakeholders supported observations on seasonal water stress and highlighted problems smallholders face accessing information and adequate inputs for tea production. Although tea provides a regular and reliable income source, smallholders may prefer to irrigate other high value cash crops and crops for home consumption. Individual water systems are likely to be used for domestic as well as agricultural use. Options for soil water conservation and small scale irrigation were explored in light of research findings. Soil water conservation measures, rainwater harvesting and treadle pump water management solutions are recommended for further investigation and piloting. Further analysis of yield and climate data would enable a finer grained understanding of geographical differences in tea yields. Investigation of factors affecting tea production such as labour time and shamba size may help to elucidate how smallholders manage tea production.

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Kayonza Growers Tea Factory estate near Butogota.

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ABBREVIATIONS

C	Carbon
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FLO	Fairtrade Labelling Organisation
LAI	Leaf area index
Ha	Hectare
HACCP	Hazard Analysis Critical Control Point
HIPC	Highly Indebted Poor Countries
HPI	Human Poverty Index
K_2O	Potassium Oxide
KGTF	Kayonza Growers Tea Factory
L	Litre
MAAIF	Ministry of Agriculture, Animal Industries and Fisheries
MWE	Ministry for Water and Environment formerly MWLE
MWLE	Ministry for Water, Lands and Environment now MWE
N	Nitrogen
NAADS	National Agricultural Advisory Development Scheme
NGO	Non – Governmental Organisation
P_2O_5	Phosphorous Pentoxide
PEAP	Poverty Eradication Action Plan
PMA	Plan for Modernisation of Agriculture
SAP	Structural Adjustment Programme.
SMD	Soil Moisture Deficit
SRC	Shoot Replacement Cycle
SWC	Soil Water Conservation
UGX	Ugandan shillings (Ugandan currency)
UN	United Nations
UTA	Ugandan Tea Association
UTDA	Ugandan Tea Development Agency Ltd.
UTGC	Uganda Tea Growers Corporation.

STRUCTURE

This thesis has six chapters. Chapter one is an introduction which gives an overview of the research problem, background and conceptual context. The research site and wider socioeconomic and agricultural context in Uganda is presented along with aims and objectives and the research approach. Chapter two is a two part literature review which covers tea production and water management. Chapter three presents methodology for climate, soil, yield and sociological research methods. Chapter four presents the findings and analysis of climate, soil, yield and sociological research. Chapter five consists of a synthesis of the research results and presentation of water management options for smallholder tea producers in light of conceptual frameworks used. This includes conclusions and recommendations for further research in the area.

1 Introduction

1.1 Background

Kayonza Growers Tea Factory (KGTF) in Uganda collects green leaf daily from 4072 local smallholders who cultivate tea over an area covering approximately 2000 ha. Tea is collected from a distance of up to 70 km from the factory at sheds located within 34 different collection centre areas. The tea is then processed at the factory and packaged ready for distribution via direct order to individual tea blenders or transported to the global tea auction in Mombassa, Kenya. The largest single buyer of Kayonza green leaf is Cafédirect, a fairtrade tea company who purchase on average, 7% of Kayonza's total production. They then blend this with leaf from other East African tea producers in Tanzania and Uganda to produce Teadirect, which is sold in the UK.

1.2 Problem

Kayonza Growers Tea Factory experiences an uneven green leaf supply pattern. Uneven supply to the factory means that the quantity of made tea produced is not consistent throughout the month or year. This affects the ability of the factory to supply buyers with adequate leaf while peaks in green leaf supply can overstretch the factory's production capacity. The quality of the leaf supplied and processed is also affected.

Successful tea production relies on consistency. This can be viewed in terms of quantity and quality. A reliable and even daily supply of green leaf is desirable in order to ensure consistent processing and production of black tea. In addition to this, consistency in the quality of the leaf supplied for production must be maintained to ensure the made tea produced meets the standards buyers' demands.

1.3 Smallholder Livelihoods

As tea is a major cash crop for Kayonza growers it is a significant component of smallholder livelihoods in the region. Inability to maintain regular green leaf production may be a consequence of smallholder vulnerability to the physical environment. This in turn may have repercussions on the sustainability of livelihoods within the region. Sustainability of livelihood is a significant tenant of the concept of fairtrade (Box.1). Smallholder's perceptions of green leaf production and the role of tea within the wider

Box 1. What does Fairtrade mean?

Fairtrade products are sold with an extra premium placed upon them. This extra income goes directly into a community social fund for local development projects with the aim of aiding the producers of the product. The aim of fairtrade is to work “towards change in international relations in such a way that disadvantaged producers can increase their control over their own future, have a fair and just return for their work, continuity of income and decent working conditions through sustainable development” (Fairtrade Foundation). As this defininition highlights, reliable and consistent economic returns for the producer is only one tenant of the fairtrade agenda. It also has broad goals for changing international relations, producer control, acceptable working conditions and sustainable development.

Why do we need Fairtrade Tea?

There are two main factors limiting an equitable tea price. Firstly, tea is still largely sold at auction which makes it vulnerable to local fluctuations in price caused by environmental or political factors for example which increase or reduce demand at a region level. Secondly, it is sold onto a global market which makes it subject to global price fluctuations. Fairtrade pricing aims to protect small-scale producers from the fluctuations in global demand and supply which make them vulnerable to market collapse and international price competition. Cafédirect describes the aims of its teadirect product thus, “to evolve support and development programmes to break this cycle of poverty, through trading” (Cafédirect, 1998-1999) . Cafedirect buys 8% of Kayonza Growers Tea Factory produce and is one of the few direct sales clients the factory has. Unlike the majority of tea trading, direct purchases are not administered via the Mombasa auction. As a result the tea producer is guaranteed an agreed price and the buyer is guaranteed their tea delivery.

farming system are pertinent to any assessment of possible technological interventions to improve green leaf yields.

1.4 Potential Solutions

Water stress is one factor which can cause a reduction in yield and leaf quality and ultimately destruction of the tea crop. As tea is often grown in subtropical environments which may have dry seasons ranging from up to four or even eight months it may require irrigation and water management strategies if maximum yields are to be obtained (Burgess, 1995). It may be possible to improve consistency of dry season yields of tea or other cash crops through improved water management practices or the introduction of small-scale irrigation technologies within the KGTF area.

1.5 Conceptual Context

Water Balance

This research is bounded by two significant conceptual contexts. One is a water balance framework which concerns the ways in which water can be retained, lost or applied on the tea shamba. Water can be lost via transpiration from the tea bush, transpiration from weeds and evaporation of water from the soil In addition to this water can be lost via runoff and drainage from the shamba. In order to maximise water use efficiency we can tackle water loss in each area. (Box 2).

Box 2. Water Balance Model

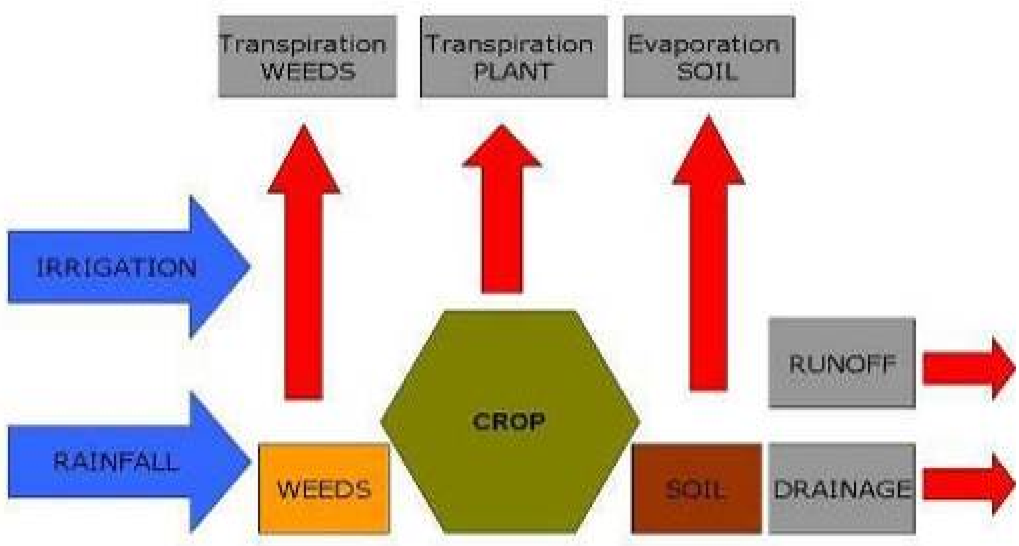


Diagram to show water balance on a tea shamba. Water loss (red arrows) and water that can be applied are shown (blue arrows).

i.) Water use can be maximised per unit of water in the soil. This can be through adoption of appropriate management practices for tea and minimising evapotranspiration from the crop and weeds.

ii.) Water may be retained in the soil. This may be through encouraging and maximising storage via control of water running off or onto a plot or rainfall conservation.

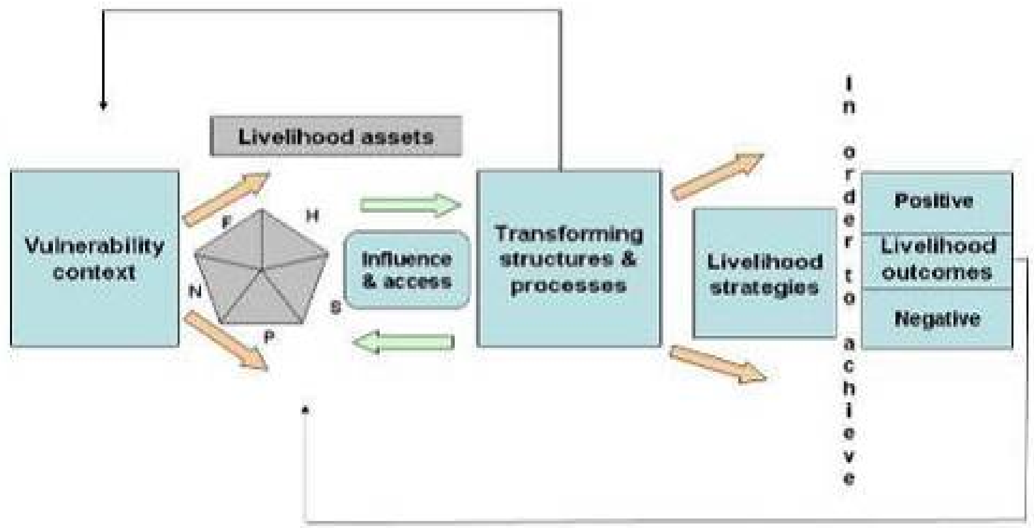
iii.) Water may be applied. Water can be conveyed or stored and conveyed from a source for application purposes in order to supplement the above measures.

Sustainable Livelihoods Framework (SLF)

Smallholders face many changes which may impact upon the sustainability of their livelihood and ability to maintain current support structures. These changes include: population increase pressure, globalization, social changes, civil unrest and the impact of national and global economic policies such as structural adjustment programmes (SAPs) (DFID, 2005). Any potential irrigation or livelihood improvement intervention must recognise these challenges and attempt to finds ways of limiting negative livelihood impacts (Barrow, 1999; Underhill, 1990).The extent to which smallholder production feeds into local, national and international economic structures is recognised as an influencing factor in water use and irrigation. The success of any irrigation project may be seen to rest not only on access to an economic market for the crop but also on an ability to improve smallholder livelihoods whether via crop yield improvement or otherwise. A Sustainable Livelihoods Framework (SLF) was used as a basis for exploring the impact of tea on smallholder assets and livelihoods and the potential for water management and small-scale irrigation to impact positively upon smallholder livelihoods (Box 3).

Box 3. Sustainable livelihoods framework

In order to investigate the role of tea and water within smallholder livelihoods a sustainable livelihoods framework (SLF) was utilised. The framework aims to provide a structure within which the main factors influencing sustainable livelihoods can be explored. This research was concerned with smallholder vulnerabilty following a key assumption within the research question that improvement of dry season tea yields could positively affect the vulnerability of smallholder livelihoods. Research was also concerned with smallholder livelihood assets and livelihood outcomes resulting from strategies presently practiced. The SLF classifies assets in terms of human, social, natural, physical and financial capital. Asset composition may vary from household to household and within communities. Assets were explored with a view to understanding if and how water management technologies might negatively or positively impact upon these areas.



Sustainable livelihoods framework adapted from DFID 2006 to include positive and negative outcomes. Where F is financial capital, H is human capital, S is social capital, P is physical capital and N is natural capital

The SLF does not include hierarchical relationships between different agents but does allow for acknowledgement of structures and processes which impact upon sustainable livelihoods. Transforming structures influencing the KGTF area may include Cafedirect, the Fairtrade Labelling Organisation and the global tea market alongside national institutions such as NAADS, the MoWE aswell as KGTF and local government. The policies and laws implemented by these institutions may be seen as transforming processes. The impact of historical processes and structures is also lacking from the framework. However, that does not preclude awareness of the historical context to the research arena. Within the Ugandan smallholder tea producer context the socio-political history of Uganda has affected tea production within Kanungu and smallholder perception of tea.

1.6 Research Site

The research site for this thesis was Kayonza Growers Tea Factory. The area supplying KGTF is hereafter referred to as the KGTF area. The factory is located next to a small trading post called Butogota within the Kayonza sub-county in Kanungu District, Uganda. Kanungu borders the Democratic Republic of Congo (DRC) to the West, Rukungiri district to the East, Kabale and Kisoro Districts to the South and Lake Edward to the North (Figure 1). At Uganda's Independence in 1962, Kanungu was known as Kinkizi County and was located within the Kigezi district. In 1974 the Runkungiri district was founded with Kinkizi County becoming one of its counties. However, in 2001 Kinkizi County became a new district called Kanungu.

Kanungu district has a population of 206 933 of which 205 095 are rural dwelling and 1838 urban (Fountain, 2005). It has a Human Development Index rating of 0.4878 placing it 28th out of 56 districts in the country (UNDP, 2005). 98% of the population are engaged in agriculture making it the dominant economic activity of the district (Kanungu District, 2006a). Major cash crops in the region are coffee, tobacco, rice and tea with tea and tobacco currently the most widely produced. The primary food crops cultivated are beans, groundnuts, rice, cassava, soya beans, sorghum, and cow peas as well as pineapples, tomatoes, onions and cabbage. Within Kanungu the sub-counties of Kayonza, Rugyeyo, Kanyantorogo, Kirima, Rutenga, Kanungu Town council and Mpungu are all engaged in tea production with 5% of their combined population engaged in tea production for KGTF.

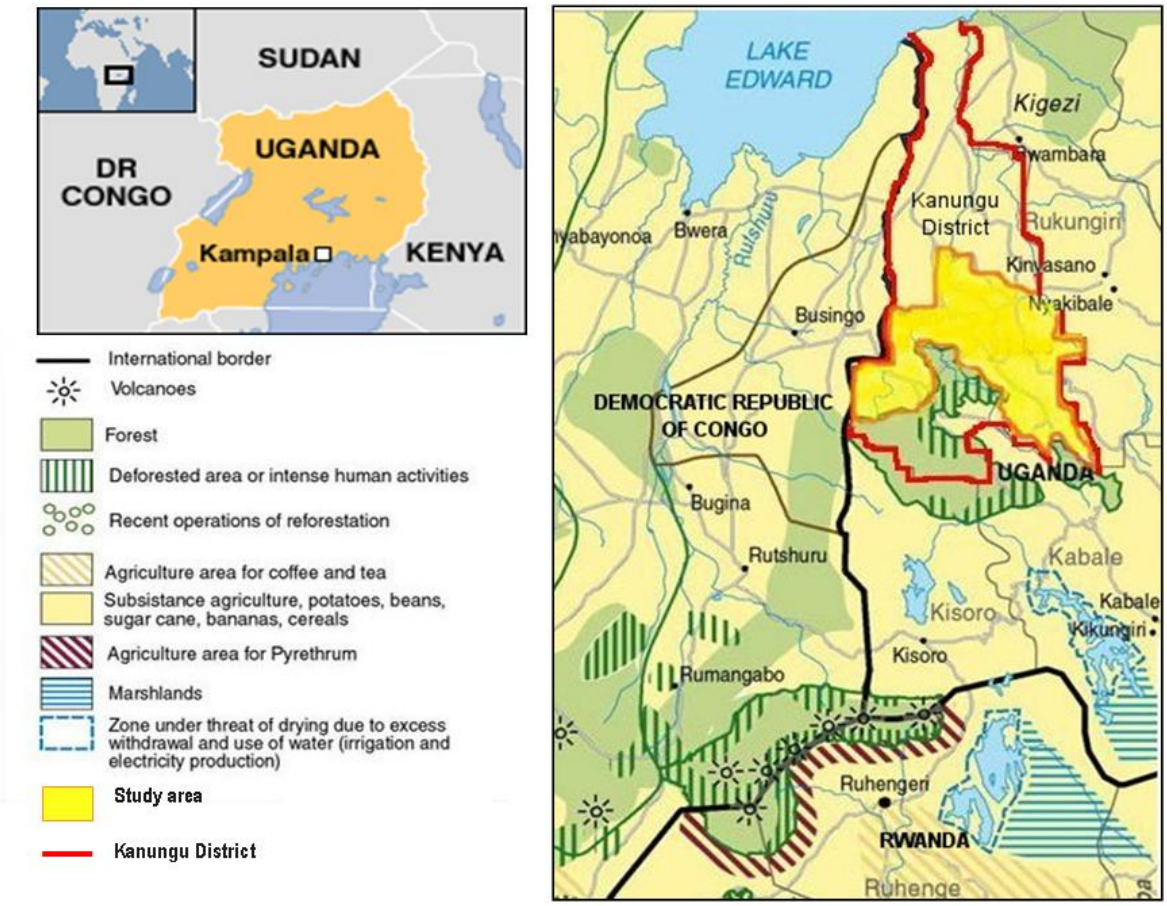


Figure 1 Kanungu district and Uganda. Adapted from (UNEP, 2006; BBC, 2006).

1.7 Uganda Socio-economic Context

Uganda is listed 145th from a total of 177 countries and ranked as a low income country by the United Nations Development Programme 2006 (UNDP, 2006). Socioeconomic indicators are summarised in Table 1. Uganda recently received debt relief as a highly indebted poor country (HIPC) under G7 debt relief for Africa initiatives and is often viewed as an economic success story in terms of its commitment to and success in liberalisation of its economy. Economic reforms have predominantly been undertaken via the implementation of structural adjustment programmes (SAPs) which have not always proved popular within Uganda (SAPRIN, 2002).

Table 1. Uganda development indicators. From UNDP, 2006.

Indicator	Uganda
State of Development	145th
Life Expectancy at birth	46.8
Total Fertility (births per woman)	7.1
Under 5 Infant Mortality (per 1000 live births)	138
Adult Literacy (Age 15 and above)	66.8 %
Population under 15 years (%)	50.4%
HIV infection rate (% population 15 – 49)	6.7

Uganda's poverty reduction strategy was launched with the PEAP (Poverty Eradication Action Plan) in 1997 (revised in 2005) setting a framework for social and economic development in the country. Water services and water development are part of this plan with water for agriculture seen to be key to improving cash and subsistence crop production. Water for agricultural production currently sits within the Ministry of Water and Environment (MoWE) formerly known as the Ministry for Water, Lands and Environment (MWLE). However, water for production is in the process of moving from this position to the Ministry of Agriculture, Animal Industries and Fisheries (MAAIF).

1.8 Agriculture in Uganda

88% of Uganda's population live in rural areas. The rural population also has the highest incidence of poverty in Uganda as graded on the human poverty index (HPI)[1] scoring 39.9 compared with 25.2 for urban populations (UNDP, 2005). Agriculture is

[1] The HPI measures deprivation according to four human development indicators which are; probability at birth of not surviving to the age of 40, adult literacy rate, percentage of population without sustainable access to an improved water source and percentage of children underweight for age. The closer the index is to 0 the closer the country is to eradicating poverty while the closer to 100 the more deprived.

the dominant source of income in these areas as it employs 78% of the economically active population in Uganda (FAO 2005) and accounts for 33.1% of Uganda's GDP (FAO, 2005). The breakdown of this contribution is as follows: food crops 71%; livestock 17%; export crops 5%; fisheries 4%; and forestry 3% (IPTRID, 1998). Tea lies within the 5% contribution that export crops make. Within the agriculture sector, smallholder plots comprise the majority of agricultural land with 80% of smallholders in Uganda possessing land that comprises less than 2ha (IPTRID, 1998). The Ugandan government's medium term plan for modernisation of agriculture (PMA) includes increase in production of crops for both home consumption and export as key aims. Water management techniques and technologies are integral to these aims.

1.9 Tea in Uganda

Tea was first introduced to Uganda in 1900. By the 1950s tea was an estate crop run predominantly by European and Asian settlers. Now it constitutes one of Uganda's biggest export crops with 37000 tonnes of tea exported in 2004 at a value of $37 million (FAO, 2006). Although, tea was predominantly a plantation crop in Uganda, 20% of Uganda's made tea now comes from smallholders (Uganda Tea Development Agency Limited).

In 1969 clone 6/8 tea was introduced to Kanungu in order to develop tea as a small-scale smallholder crop (Uganda Tea Development Agency Limited). However, production ceased from 1973 until 1985 due to political upheaval. A ten year EU rehabilitation project which started in 1989 enabled tea production and processing to resume at KGTF once more.

1.10 Aims & Objectives

The aim of the research was to determine the potential for rainwater harvesting, water storage and small-scale irrigation to improve smallholder livelihoods in the area of Kayonza Growers Tea Factory in Kanungu, Uganda. The specific objectives of this research were to:

- Review literature to develop an appropriate framework for research.
- Characterise the perceived problem and its underlying causes.
- Identify the viability of appropriate water related management and optimisation technologies for tea in the context of smallholder livelihoods.

1.11 Approach to Research

This research did not start with a specific hypothesis but rather as an open ended investigation allowing for fluidity in research methodology. Field research was conducted over a period of 5 months from April until September 2006 at Kayonza Growers Tea Factory in Kayonza sub-county. The approach taken can be viewed in three main sections.

i. Climate and yield data was collected in order to investigate possible correlations between yield and water stress with the aim of supporting or refuting perceptions of yield fluctuations within the KGTF area.

ii. Smallholder perceptions of yield fluctuation and tea production were investigated in order to obtain stakeholder perspectives with regards to the problem and ascertain the impact of this on smallholder livelihoods in the area.

iii. Management and technology options were considered using yield and water balance modelling in combination with social and agroforestry survey techniques to explore the viability of different interventions.

2 Literature Review

2.1 Tea Production

A great deal of literature exists concerning tea management practice in East Africa. However, there is a paucity of literature concerning tea in Uganda. Therefore, much of this review is concerned with research results from Tanzania and Kenya. This review discusses the growth and physiology of tea then the agroclimatological factors which limit its physical growth. It then looks at the effects of different management strategies including plucking regime and soil maintenance. Yield and dry matter production are explained. Finally, drought tolerance and irrigation considerations for the tea plant are discussed.

Growth, yield and quality of tea

Tea (*Camellia sinensis* (L.) O. Kuntze) is a member of the Theaceae family. Tea is a perennial evergreen shrub which is thought to be descended from sub-tropical under story and montane plant species. There are two varieties of tea cultivated for consumption, var. *assamica*, the Assam variety and var. *sinensis,* the China variety (Bonheure, 1990). The Assam variety which has broader leaves and a more tree-like habit than the China variety is the most commonly cultivated in Uganda. Tea is grown commercially for its young shoots which tend to comprise two or three leaves and an apical bud. Shoots are generally plucked by hand at weekly to monthly intervals and transported within the same day to the tea factory where they are cut and dried to produce tea for drinking.

The Assam tea plant (*C. sinensis var. assamica*) can grow to a height of 15 m if unpruned (Bonheure, 1990). A seedling tea plant possesses a taproot which can reach between 0.9 and 1.5 m depth (Allen et al., 1998). However, Stephens and Carr report that roots of clonal tea in Southern Tanzania can extend to a depth of 6 m (Stephens and Carr, 1991). Rooting depth and root distribution are important characteristics of the tea plant as they affect the ability of the plant to uptake water and thus influence growth.

The growth cycle of tea is known as the “banjhi cycle” and shoots with dormant apical buds are named banjhi shoots (Tanton, 1992; The Tea Board of Kenya, 1986). Within the growth cycle of tea there are two distinct growth phases, a productive growth or flushing period and the "dormant phase" (Bonheure, 1990). The "dormant" phase is marked by internal activity for the bud. The bud grows larger and lengthens forming sexual bracts, then pre-leaves and regular leaves (Bonheure, 1990). Maximum development is indicated by the appearance of a small bud approximately 5 mm in length by the terminal leaf of a shoot. Peaks and troughs in the growth cycle were once though to be caused by dormant buds. However, it has been shown that fluctuations in crop production can be synchronous with shoot growth thus demonstrating that the dormancy and flush cycles in tea are independent (Fordham, 1977). Therefore, removing factors limiting shoot growth can encourage a more stable flushing period (Tanton, 1992).

Yield and dry matter production

The harvested part of the tea plant consists of the shoots and leaves. A principal aim of tea production is to obtain good quality high yields. Yield is characterised by number of shoots per unit area, the rate of shoot growth and their average dry weight at harvest (Carr and Stephens, 1992). The number of shoots per unit area is partly genetically determined (Tanton, 1992)(Stephens and Carr, 1994).

$$\text{Yield} = \begin{matrix}\text{mean total shoot}\\ \text{population density}\\ \text{per year}\end{matrix} \;\mathbf{X}\; \begin{matrix}\text{number of shoot}\\ \text{replacement cycles}\\ \text{per shoot}\end{matrix} \;\mathbf{X}\; \begin{matrix}\text{mean dry}\\ \text{mass}\end{matrix}$$

Dry matter

The yield of tea can also be derived from the product of incident short-wave solar radiation (S), the proportion of solar radiation intercepted (f_S), the solar radiation conversion ratio[2] (ε_S), and the harvest index (HI) (Burgess and Carr, 1996).

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$$Y = S.\, fS\, .\, \varepsilon_S\, .\, HI \qquad \text{..................................(Equation 1)}$$

[2] Synonymous with Radiation Use Efficiency (RUE).

High yields can be achieved by maximising partitioning to the harvestable leaves whilst not compromising the root structure which supports water and nutrient uptake.

Incident solar radiation may vary according to altitude. Canopy area expansion affects the extent to which the plant is able to maximise light interception thus increasing photosynthesis and so dry matter production also (Carr and Stephens, 1992). Canopy cover is expressed through the leaf area index (LAI) which is synonymous with green area index (GAI). Tea is harvested from mature plants, therefore, in plants not suffering from drought stress changes in leaf area over the course of a year are minimal. The literature suggests that the leaf area index (LAI) for tea is between 5 and 6 (Ng'etich and Stephens, 2001; Barua, 1989). However, Ng'etich and Stephens also reported changes in LAI over the course of 2 years from an initial LAI of 2.2 minimum to a maximum of 6.1 (2001). In addition to this there were slight differences in the LAI between different clones and at different sites. Recorded solar radiation conversion ratios vary from 0.25 to 0.6 g MJ^{-1}(Ng'etich and Stephens, 2001; Magambo and Cannell, 1981; Burgess, 1996a.). Solar radiation conversion has also been shown to vary seasonally (Ng'etich and Stephens, 2001). Values of 0.4 to 0.6 MJ^{-1} are commonly found in the literature.

Harvest index (H.I) refers to the proportion of dry matter partitioned to harvestable components of the plant which in the case of tea are the shoots. The Harvest index values for tea vary considerably from 7 – 24% with high yielding clones partitioning more dry matter to the top of the bush than low yielding clones (Ng'etich and Stephens, 2001; Ng'etich and Stephens, 2001). Harvest index values for clone 6/8 range from 8% in Kericho Kenya to 24% in Tanzania (Magambo and Cannell, 1981; Burgess, 1994). Harvest index values can be influenced by clone, altitude and temperature.

Quality

Quality is a subjective characteristic related to appearance, aroma, astringency and flavour. Teas in some parts of Africa are classed as plain which means they lack aroma (Owuor, 1997). In this case they tend to be priced according to appearance, flavour and astringency. These qualities are influenced by theaflavin, thearubigin and caffeine content of tea (Owuor 1995 in Owuor 1997).

The main factors affecting leaf quality are environmental stress and poor management strategies. Environmental factors affecting leaf quality may be due to climate. Excessive sun exposure coupled with lack of water leads to dry drought stressed plants and leaves while hail storms may cause bruises and tears in leaves making them unsuitable for production. Diseases and pests can also affect leaf quality and appearance.

Management factors affecting quality may include ill-timed plucking regimes resulting in leaf which is too old and fibrous. Poor plucking can also lead to stems and 3 or 4 leaves and a bud being plucked. Lack of herbicide application will affect plant growth by forcing the plants to compete for nutrients and water in the soil with weeds. This too has an impact on leaf quality.

The highest quality tea is made from tender actively growing shoots (Willson, 1992). Leaves lower down the stem and the woody parts of the bush create an inferior taste, unacceptable to consumers (Willson, 1992). In Uganda tea is classified according to 6 grades[3]. These are classed according to the size of granule, colour of granule and how much fibre is in the produce. The finer and less fibrous grades such as PF1 tend to fetch higher prices at auction. Production of finer grade teas requires young shoots and leaves for production

[3] Tea in graded according to the appearance of the final product. Ideally the tea grains should be even in size and free of fibres. African teas are either or BP1 (Broken Pekoe), PF1 (Pekoe Fannings), PD (Pekoe Dust), D1 (Dust 1), F1 (Fannings 1), or D (Dust). Finer grained tea with few fibres such as BP1 tend to fetch a high price while PD grades (sometimes called sweepings) which may contain a lot of fibres fetch a lower price. Different grades may be chosen to give different characteristics in a cup of tea such as colour or sharpness.

Climate and soil

Tea development, growth and yield is affected by rainfall, temperature, solar radiation and humidity. Description of these factors follows.

Temperature

Tea has an ideal temperature range either side of which shoot growth (and consequently yield) decreases. Tanton (1979) demonstrated that in moist air shoot growth rate is directly proportional to shoot temperatures from 12˚C to 36˚C. The minimum or base temperature for growth (Tb) is around 13˚C while the maximum ideal temperature (To) is 30˚C (Carr and Stephens, 1992). Within these limits shoot growth will increase linearly (Carr and Stephens, 1992). Cooler temperatures have been shown to affect the proportion of dry matter partitioned to the harvested part of the tea plant (Burgess, 1996a.).

The relationship between shoot growth, minimum temperature and time is encapsulated in the concept of thermal time. Thermal time is a measure of how long different growth processes take when water is not limiting and the crop is not sensitive to day length (Carr and Stephens, 1992). For example, in Malawi a 475 ˚Cd above the base temperature of 12.5˚C is needed for a bud to grow from apical dominance to three leaves and a bud (Carr and Stephens, 1992). The frequency with which new shoots to appear on a bush is called the shoot replacement cycle (SRC).

Altitude

Increases in altitude affect temperature (Carr and Stephens, 1992). For each 100 m increase in altitude a 0.6˚C decrease in temperature is likely (Carr and Stephens, 1992). Yield decreases at altitudes above 1700 m and is more pronounced at altitudes above 2200 m (Carr and Stephens, 1992). Therefore, altitude can have a limiting effect on tea yields via increased length of the SRC. However, although limited in terms of yield, tea grown at high altitudes is considered to be of better quality than that grown at low altitudes.

Solar radiation

Solar radiation can exceed 1000 W m^{-1} at high altitudes near to the equator (Carr and Stephens, 1992). However, approximately 20% of this is reflected from the surface of the crop back into the atmosphere while another 20% is emitted as long wave radiation (Carr and Stephens, 1992). This leaves around 600 W m^{-1} net available energy for the tea canopy surface. A small proportion of this energy is used in photosynthesis while the majority is latent heat[4] or sensible heat[5] (Callander and Squire, 1981). This may have an impact on leaf temperatures and consequently leaf-to-air saturation vapour pressure deficits which can affect shoot extension rates and potentially yields (Carr and Stephens, 1992). Intercepted solar radiation was shown to vary by as much as 30% at different sites on the Kericho estate in Kenya (Ng'etich and Stephens, 2001). Lower solar radiation interception rates there were also linked to low dry matter production (Ng'etich and Stephens, 2001). However, this was not directly correlated to yields. The proportion of solar radiation intercepted (*fs*) is determined by crop cover and LAI. In addition to this solar radiation may be affected by altitude due to differences in cloud cover (Ng'etich and Stephens, 2001; Ghosh and Kumar, 1999).

Humidity and Saturation Vapour Pressure Deficit (SVPD).

Transpiration is determined by the vapour pressure difference between the evaporating surface within the leaf and ambient air and water vapour conductance. Saturation vapour pressure deficit (SVPD) encapsulates this relationship. SVPD affects tea yields by increasing the leaf transpiration rate and can occur even when soils are at field capacity (Carr and Stephens, 1992). As the saturation vapour pressure deficit affects transpiration it influences the ratio of dry matter to transpired water. Saturation vapour pressure deficit is a measurement of air dryness and is consequently closely linked to humidity.

[4] Heat dispersed via evaporation Callander, B.A., Squire, G.R., 1981. Tea plantations. In: Kozlowski, T.T. (Ed.) Water Deficits and Plant Growth. Academic Press, New York..
[5] Sensible heat is heat of the air Ibid. In..

A high SVPD is associated with high temperatures and dry air which can limit tea growth. The critical SVPD for tea is 2.3 kPa beyond which shoot growth and consequently yield is significantly depressed (Tanton, 1982). At high temperatures of 25˚C or 30˚C this corresponds to relative air humidity of 28% or 45% (Carr and Stephens, 1992). As tea is particularly sensitive to dry air conditions, irrigation may not be able to substitute for rainfall entirely (Carr and Stephens, 1992).

Rainfall

How often rain occurs and its distribution throughout the year is important for growth of tea. Tea is usually grown in regions with rainfall between 1300 and 2200 mm per year (Ng'etich and Stephens, 2001). Ideal minimum monthly rainfall is between 120 and 150 mm (Owuor, 1997; Othieno, 1992).

Drought

Tea is considered to be a drought intolerant plant and its water use can be variable (Tanton, 1992). Rates of crop water use decrease once the water deficit has exceeded a critical deficit point. The critical deficit value will vary according to water stored in the soil, the ability of the plant to access the water stored in the soil via its roots, water applied to the soil in the form of irrigation or rainfall, water lost from the soil via drainage and evaporation and the transpiration rate of the plant. The response of tea to soil moisture deficits has been studied. For example, Stephens and Carr in Ngwazi, Tanzania found that the daily rate of transpiration for a mature clone 6/8 was equivalent to the potential evaporation rate until the soil water deficit (SWD) reached a critical deficit of 60mm. After this transpiration decreased linearly until zero when all extractable water within the rooting zone had been used (Burgess, 1995). Estimates of available extractable water varied from 114 mm for a root depth of 1.5 m and 157 mm for a root depth of 2.2 m (Burgess, 1995). However, rooting depth of a tea plant may be as little as 1 m which will restrict the area available to the plant for water uptake (Allen et al., 1998). Large soil water deficits can lead to drought stress in the plant and reductions in yields of green leaf. Tea yield response to drought stress as measured by soil moisture deficits was found to be curvilinear (Stephens and Carr, 1989; Nixon et al., 2001). Within soil containing an estimated 330 mm of readily available water

(RAW) (assuming rooting depths of 5.5 m not confirmed in the study) annual yield losses per unit of water deficit were found to increase slowly to a 1 kg ha^{-1} loss at a 300 mm deficit then more rapidly to a 6.5 kg ha^{-1} loss at 600 mm deficit (Nixon et al., 2001). Seasonal responses are likely to be more pronounced than this.

The negative effect of drought on shoot growth means that the total proportion of dry matter partitioned to roots is likely to increase as partitioning to leaves, stems and shoots decreases (Burgess, 1996). This will affect yields obtained by decreasing the proportion of dry matter partitioned to harvestable parts of the tea bush. This has been demonstrated by a reduction in harvest index. Burgess and Carr found that harvest index fell from 17% in irrigated plots to 8% in those which were drought stressed (Burgess & Carr, 1996).

Physiological responses to water stress include extended root growth in an attempt to reach any available soil moisture at the expense of canopy development and reduced transpiration. Drought response may also vary according to clone. Burgess and Carr observed that clone 6/8 was more prone to defoliation when drought stressed than the other cultivars they observed (1996). By defoliating the plant is able to regulate transpiration. However, the effect on yield in a season can be severe. Interestingly, annual green leaf yields were not found to vary under drought stress. Annual distribution but not quantity was affected. However, sudden flushes in leaf production may pose difficulties for smallholders who must find additional labour in order to pluck all the leaf produced by the bush. Drought stress in young tea plants can make them susceptible to infections such as *Phomopsis theae* which can affect both quality and quantity of leaf produced (Carr and Stephens, 1992).

Soil

Tea has several requirements from the soil it inhabits. It prefers to grow on acidic soil with a pH of between 5.0 and 5.6 being ideal (Tanton, 1992; Othieno, 1992). Soils with a pH above 6.5 are considered unsuitable for tea and even those above 5.6 may require correction (Othieno, 1992). In addition to Oxygen, Hydrogen and Carbon which are present in the air, the principal nutrients required for tea (and any other green plant) are

Nitrogen, Phosphorus, Potassium, Calcium, Magnesium and Sulphur. Aluminium has also been shown to be essential for tea growth (Othieno, 1992). An ideal tea soil is that which is deep and well drained with a minimum available depth of 2 m giving an acceptable potential depth for available water in the soil (Othieno, 1992). Water holding capacity of the soil is also affected by soil type, texture and aggregation.

Tea management strategies

Any irrigation strategy for tea assumes that the crop is under optimal management. Therefore, a discussion of management strategies for tea is beneficial. Tea plants take 3 years to mature after planting out at a 1 year old seedling stage. Although tea can be harvested prior to maturity yields tend to be low. Management of a tea crop necessarily focuses on establishing the crop and then appropriate maintenance. This can be split into five distinct areas of activity which are; Bringing into bearing, maintenance pruning or skiffing, plucking or harvesting regime, fertilizer application, and pest, weed and disease control. Summaries of these aspects of tea management and their potential effect on yield are given below.

Bringing into bearing

The process of shaping bushes to form an even density of shoots for plucking is called bringing into bearing (Willson, 1992). This involves pruning different levels of the bush and/or pegging them. Pegging involves fixing branches horizontally to encourage the bush to grow in the desired shape creating a broad even plant cover. The process of bringing into bearing can affect the future development of the crop and if not done competently can lead to lack of complete ground cover

Maintenance pruning or skiffing

The plucking table for tea bushes is usually set at a maximum of 70 cm (Bonheure, 1990).Without pruning the plucking table will continue to rise to ensure sufficient active leaves for crop production (Willson, 1992). Therefore, it is necessary to prune the tea bush (usually to a height of 45 cm) when the pruning level is too high (The Tea Board of Kenya, 1986). The prunings may be left on the soil to form a mulch which can help to improve soil structure and water conservation (Bonheure, 1990; The Tea Board of Kenya, 1986).

Pruning should ideally be done when the plant is not stressed. If pruned during the dry season plants are more prone to scorching and have fewer energy reserves to regenerate quickly (The Tea Board of Kenya, 1986). To this end, prunings should be left on the shamba to protect newly pruned bushes, help prevent soil erosion and to decompose thus improving soil structure and nutrient content (Bonheure and Willson, 1992). Removal of prunings has also been associated with yield reductions in the cycle following the prune (Grice and Malenga 1987 in (Bonheure and Willson, 1992). Skiffing is a form of light pruning which is usually performed on overgrown tea bushes.

Harvesting regime

Tea is harvested from the top section of an actively growing stem. The shoots harvested usually consist of two or three leaves and a bud (Willson, 1992). In practice, plucking may also involve the removal of banjhi shoots (dormant buds), leaves and bud shoots, broken shoots and detached leaves (The Tea Board of Kenya, 1986). An adequate plucking regime should aim to supply the processing factory with sufficient leaf suitable for manufacture (The Tea Board of Kenya, 1986).

The plucking interval is important in terms of maximising yield quality and quantity. Shoots are usually plucked every 7 – 10 days (Bonheure, 1990; Barua, 1989; Asimwe, 2006). However, this interval may be longer in locations with lower temperatures or other limiting factors. A longer interval within non limiting temperatures in the range of 14 days has been shown to give greater yields but at the expense of quality (Willson, 1992). However, in some situations it has been shown that a short round gave the highest yields in clonal and seedling tea (Dumur and Naidu 1985 in Willson, 1992). Research suggests that a three shoots and a bud plucking strategy produces a greater yield than a two shoot and a bud strategy. Bonheure claims that plucked yield may be increased by around 25% through this plucking technique (Bonheure, 1990). However, this would have a deleterious effect on the quality of the leaf produced. The frequency with which plucking takes place, known as the plucking regime also affects the quality and quantity of tea produced. Tanton demonstrated that an increase from 7 to 14 days between plucking led to a 38% increase in yield (Tanton, 1992; Tanton, 1979). However, this is at a cost to the quality of the tea obtained as it is older and more fibrous than the younger shoots. Greater yields can be achieved through modification of harvesting practice. However, an approach to production that focuses only on the maximum kg per ha achievable is likely to neglect the quality of the tea leaf produced (Tanton, 1992). Therefore, a harvesting regime must necessarily attempt to balance quality with quantity of leaf.

In regions close to the equator such as Southern Uganda, the largest yield flushes occur at the start of the dry season (Carr and Stephens, 1992). An important aim in tea management is to minimise variations in yield throughout the year. This can only be achieved in part with irrigation (Hanna, 1971).

Fertilizer application

As tea is usually grown as a long-term monoculture crop, soil fertility is likely to deteriorate over time (Bonheure and Willson, 1992). Therefore, fertilizer application is usually necessary. Othieno reported that in order to produce 1000 kg of dry tea, clone 6/8 removed 40 kg N[6], 4 kg P_2O_5[7] and 19 kg K_2O[8] (1979 in Bonheure and Willson, 1992). High ratios of N to K have been shown to lead to high yields (Ranganathan et. al in Bonheure and Willson, 1992). A directly proportional relationship between N application and yield increase exists in unshaded tea at applications of up to 150 kg per ha (Bonheure and Willson, 1992). After this point the response is reduced although in Kenya tea yields were found to respond to N application at up to 500 kg N per ha (Bonheure and Willson, 1992). In addition to deficiencies of NPK, tea may suffer from nutrient and micro-nutrient deficiencies due to lack of zinc, sulphur, calcium, magnesium and copper. The most critical of these are calcium and magnesium. As tea prefers acidic soils in the pH range of 5.0 to 5.6, correction of soil may be necessary

[6] Nitrogen.
[7] Phosphorous Pentoxide (Ash).
[8] Potassium Oxide (Potash).

(Willson, 1992; Othieno, 1992; Bonheure and Willson, 1992). Application of organic manure has the potential to improve not only nutrient content of the soil but also soil structure thus aiding water retention and preventing runoff.

Pest, weed and disease control

Appropriate management of tea involves ensuring appropriate pest, weed and disease control. This may come in the form of herbicide and pesticide application or management techniques to minimise disease. Ideally, tea has a full ground cover when mature which minimises weed colonisation. Therefore, herbicide should only be required when tea is being established to prevent weeds from competing for nutrients and water in the soil.

Constraints to smallholder tea production

Uganda may have the potential to produce the highest yields of tea in East Africa (Carr, 1993). However, the tea industry is still recovering after the near cessation of tea production in the 1970s due to political instability. Carr recognises several management and labour constraints on African smallholder tea producers:

- Lack of sound technical and managerial advice particularly when establishing a shamba.
- Pruning instead of pegging bushes during establishment. The benefit of this is to bring a plant into bearing faster but possibly at the expense of later productivity.
- Hoeing weeds instead of using herbicides. This is more cost effective for smallholders but risks damage to tea bush roots.
- Herbicide use may be ineffective on a small shamba due to the proximity of other crops and weeds which can recolonise more easily than they would on a large estate.
- Inability to access timely fertilizer.

Labour constraints identified by Carr include:

- The high labour requirement for plucking which is compounded by the inability of smallholders to compete with factory benefits for pluckers.

- Collection centres may collect early in the day to deliver leaf to the factory. This limits a smallholder's plucking day meaning he must obtain as much leaf as possible in a short space of time.
- The time it takes to transport leaf from the field to a collection centre can be up to 2 hours.

In addition to these constraints the Ugandan tea industry is also constrained by elderly tea plantations that may need replacement and a lack of improved planting material to offer to smallholders (Aluka and Hakiza, 2001). The wider economic structures which affect global fluctuations in tea prices in conjunction with Uganda's agriculture policy and political context are also acknowledged as factors constraining smallholder crop production (Carr, 1993; Aluka and Hakiza, 2001; Blake et al., 2002).

Summary

Tea yield can be viewed in terms of quality and quantity. Young shoots of the tea bush comprise the yield. Environmental aspects of tea production affecting yield and quality are as follows:

Temperature. Temperatures between 13˚C and 30˚C are ideal. Altitude limits temperature by around 0.6˚C for each 100 m increase but is often considered to be better quality.

Solar radiation. Low solar radiation interception is linked to low dry matter partitioning. Latent and sensible heat from solar radiation may also affect leaf to air SVPD thus affecting shoot growth and yield. Available solar radiation can also be affected by altitude due to increased cloud cover at high altitudes. The proportion of solar radiation intercepted by the canopy (*fs*) is taken to be 0.99 for mature tea assuming full crop cover. This is a product of leaf area index and crop cover %.

SVPD. The critical saturation vapour pressure deficit value for tea is 2 kPa. SVPD affects transpiration and therefore dry matter production per unit of water.

Rainfall. Ideal rainfall conditions for tea are between 1300 and 2200 mm annual rainfall with a minimum of 120 – 150 mm each month.

Ideal soil pH for tea is between 5.0 and 5.6.

Soil water available to tea is dependent on root depth and water holding capacity of the soil.

Management techniques for tea include bringing into bearing, maintenance pruning or skiffing, plucking and harvesting regime, fertilizer application and pest, weed and disease control.

Recommended management practices vary according to the environmental context, the age of the tea bush and clone. If management of tea is optimal then it may be beneficial to consider water management strategies that could help to improve dry season tea yields.

2.2 Water Management

If management of tea is optimal then it may be beneficial to consider water management strategies that could help to improve dry season tea yields.

Defining water management and small-scale irrigation (SSI)

Definitions of irrigation are important to the way in which any study of water management is approached. Irrigation is not easy to define or categorize and yet how one defines irrigation will have considerable impact upon methodology used and subsequent conclusions and recommendations (Underhill, 1990). In 1987 the FAO defined irrigation as “the application of water supplementary to that supplied directly by precipitation for the production of crops”. However, recent publications include discussion of water conservation measures and rainwater harvesting alongside consideration of technologies for application of water (Carter and Danert, 2006). Within this thesis small scale irrigation refers to the application of low technology irrigation solutions suitable for use on smallholder plots. Solutions should ideally be environmentally, economically and socially sustainable. It is recognised that strategies for maximising soil water as well as soil water management constitute forms of irrigation in that they serve the same purpose of maximising water available to the plant (Barrow, 1999; Carter and Danert, 2006; Savva and Frenken, 2002). This thesis takes a similarly broad definition of irrigation. However, a distinction is made between *in situ* and *ex situ* water use. *In situ* is defined as use of water already present as a means of maximising soil water availability. *Ex situ* is defined as water off site which may be either conveyed to the plot or collected on the plot from an external source such as rainwater or a stream source. As this study is concerned with smallholder production it is recognised that water management strategies may include both *in-situ* and *ex-situ* water use.

Smallholder Soil Water Conservation Strategies

Despite the fact that soil water conservation (SWC) is viewed to be low cost with fewer potentially negative impacts than large scale irrigation projects they have not seen the same level of investment within agricultural development schemes (Barrow, 1999).

Recent criticism of SWC interventions within development has highlighted lack of adequate support in implementing and maintaining structures and lack of recognition by development practitioners of the labour and time required for SWC activities (Tripp, 2006). This can result in long-term damage to agricultural systems (Tripp, 2006).

SWC practice may involve use of a variety of construction and management techniques including contour ridge construction bunding, ridged terraces, ponds and trenches, organic manuring and mulching in order to manage cultivated land. However, the extent to which measures are applied varies. General SWC methods may include the following:

- Use of on-farm manure to improve soil quality.
- Use of other available organic materials to improve soil quality.
- Legume rotations and use of improved drought resistant varieties to maintain soil quality and maximise crop success.
- Creation of Zero slope contours, tied ridging, infiltration pits and other relevant rainwater harvesting techniques to maximise use of all available water.
- Timely land preparation and planting to maximise use of good soil moisture (Savva and Frenken, 2002; Annan, 2005).

Runoff farming is one form of combined SWC and rainwater harvesting that tends to be employed in areas where there is variable and uncertain rainfall which hinders production of subsistence crops (Savva and Frenken, 2002). It involves the collection of rainwater runoff from a large area which is then channelled to a much smaller growing area. This may be undertaken in a variety of ways via construction of channels, bunds, trenches and reservoirs which can also be defined as surface irrigation techniques.

Soil Water Conservation & Tea

Soil erosion has the potential to cause a decline in soil fertility. The severity of soil erosion increases with rainfall intensity and run-off (Othieno, 1992). However, the extent of mulch ground cover and tea crop canopy cover will affect the occurrence and severity of run-off and soil erosion (Othieno, 1992). Othieno demonstrated that when tea plants have a uniform ground cover of 60% or above run-off and soil erosion are negligible (Othieno, 1992). Therefore, SWC methods tend to be concerned with young tea which has a lower ground cover. Nevertheless, mature tea shambas may also have low ground cover and so suffer from associated erosion problems.

Recommended soil water conservation measures for tea include:

- Contour bunding using stone, grass and earth constructions.
- Terrace and micro-catchment constructions such as lock and spill drains.
- Mulching with grasses during establishment and post-pruning.

(The Tea Board of Kenya, 1986; Othieno, 1992; Othieno, 1981; Shaxson, 1971).

Water Application

If water is to be applied for irrigation, storage methods, modes of conveyance and pumping mechanisms may or may not be employed. Figure 2 shows elements to consider in an irrigation system. Pumping and storage may or may not be required at each stage.

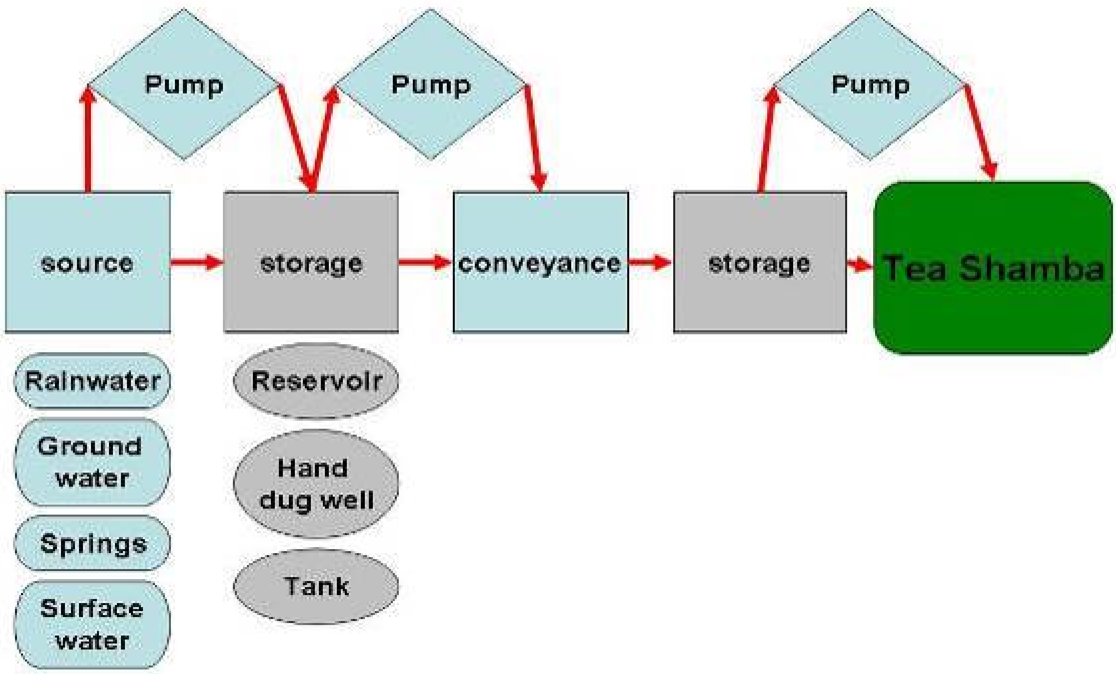


Figure 2. Key components to consider in the layout of an irrigation system. Pumping and storage may or may not be required in each stage..

Water Sources

Rainwater

Rainwater harvesting for agriculture can be defined simply as the collection of water runoff for productive use (Ngigi S. N, 2003). This is one of the oldest methods of water collection and can be found in many smallholder water use systems ranging from wadi systems in North Africa to terraced reservoir systems in India (El Sammani et al., 1996; Pacey and Cullis, 1986). Rainwater harvesting covers a broad spectrum of water management practices. Water may be directed from a larger surface or runoff area onto a smaller growing area as is the case with runoff farming or may be as simple as placing a cooking pot outside during a rain storm. Rainwater can be channelled in a variety of ways using intricate canal and terracing systems to transport water for some distance or via diverting structures. Water collected from rainfall can also be used to supply a manual bucket or tank for a low head drip irrigation system. In Uganda rainwater harvesting is utilised for domestic water purposes. However, it is not used on a formal scale for agriculture.

Groundwater

Groundwater is the source for the majority of domestic water used in Uganda. Productive aquifers are mainly found in the weathered bedrock layer overlying crystalline basement rock and in fractures and faults in the basement (IPTRID, 1998). Rates of extraction for hand pump fitted boreholes within the country are between 0.6 and 1.2 m^3 (IPTRID, 1998). Within Kanungu groundwater is the main source of domestic water supplies via protected spring water and gravity water supply. However, rainwater collection tanks, shallow wells and deep boreholes are also used (Government of Uganda, 2005). No statistics are available on groundwater exploitation for agriculture in Uganda. However, valley tanks are used in some areas for both domestic and livestock use. Nevertheless, formal development of this resource has not been extensive. Recent authors suggest that groundwater is under utilised in sub-Saharan Africa (Giordano, 2005). Sustainability of groundwater supply is dependent on the ability of underground aquifers to recharge. This will be affected by the geology of the area and the technology available to exploit such a resource.

Springs

Springs are a form of groundwater. However, they may be developed in a manner distinct from other groundwater sources. 12 000 springs have been identified for development within the country and the government is keen to exploit this resource further (FAO, 2005). 4500 protected springs are currently present in the country. Springs may be unprotected or more commonly protected by clearing vegetation from the spring source and fencing to prevent livestock from contaminating the area, connecting the water source to piping underground and creating a concrete apron area for easier collection and cleaning.

Surface water

Surface water sources may be included in discussion of groundwater as are likely to be derived from groundwater sources. Surface water sources may include streams, rivers, wetlands or ponds. Within East Africa furrow irrigation systems are commonly used to divert water from a hillside source such as a river by gravity to a lower cultivated area (Adams, 1992). Wetland swamp and valley cultivation for irrigation is one of the most common forms of irrigation in East Africa (Adams, 1992).

Water lifting

It may be necessary to utilise a water lifting technology to obtain water for irrigable land. For example, water could be pumped from an existing water source such as a river, stream or lake to the irrigation site.

Manual

Manual lifting technology may be as simple as moving water using a bucket or jerry can from a well or river or may involve the use of a pump. Manual water lifting pump technology has been successfully introduced to African sub-Saharan countries such as Kenya, Niger and Zimbabwe for both domestic and agricultural use (Underhill, 1990; Kay, 2001; Musa, 2005). Technologies such as the treadle pump and rope pump have been designed and promoted in these countries with smallholder markets in mind. Treadle pumps are based on suction lift principals using a piston and cylinder to draw water up from a lower source (IPTRID, 2000). Treadle pumps available for agriculture in Africa are based on a Kenyan design which is modified to enable them it to be used as a pressure or suction pump (IPTRID, 2000). A manually operated water lifting pump such as this has a total pumping head of about 14 m. Maximum suction lift is about 7 metres. As there is a direct relationship between the two, delivery pressure under maximum suction lift is reduced to 7m. This would affect the rate at which water can be applied to a crop and also the amount of time and energy demanded from the operator. Advantages of this type of pump are that it may be operated using the hands or feet and can be used by both children and adults enabling all available labour to be used.

Motorised

A motor can be used in order to enhance total pumping head by increasing pressure although suction lift remains the same. The fuel costs for motorised pumping preclude many smallholders from utilising this type of technology. For this reason it is a technology usually recommended for large hectare landowners and those who have a regular and reliable source of income sufficient to purchase fuel (Savva and Frenken, 2002).

Water Storage

A means for water storage may be required if water is to be collected for later use. Water storage devices can include technologies such as hand dug wells which enable collection of water from a spring to a pool or larger lined reservoirs.

Conveyance

Irrigation requires conveyance of water from source to field. Methods of conveyance depend on the distance of a water source to the irrigable land and the terrain the water must travel to reach there. Conveyance using gravity may be via canals or pipes. Canals or channels may be constructed from earth and may require lining to minimise losses via seepage (Carter, 1989). Pipes are generally plastic or steel in SSI contexts.

Water Application Methods

The application of water for irrigation can be broadly categorised in the following manner:

Surface – Moving water over the land in order to wet the surface and ultimately infiltrate into the soil.

Sprinkler – Moving water under pressure via a system of pipes to be applied via sprinkler heads.

Localised – Moving filtered water or fertilizer under low pressure via a pipe system directly onto or into the soil in small amounts.

Sub-surface – Raising or lowering of the water table to affect groundwater flow to the root zone. This is essentially a drainage management technique.

A brief summary of the first three methods is given below;

Surface Irrigation

Surface irrigation methods account for approximately 95% of the world's irrigation (Kay, 2001). One example of surface irrigation is swamp irrigation. This could also be classed as a water storage technique. According to Pacey and Cullis's classification of rainwater and floodwater harvesting systems, surface irrigation involves water storage via soil at saturation (Pacey and Cullis, 1986). Swamp irrigation is probably the most common form of smallholder irrigation currently utilised informally in Uganda. In addition to this river or stream diversions may be used in conjunction with bank construction, gulley rehabilitation and bunding. Swamp irrigation utilises existing wetlands and their stream sources to divert water into channels for irrigation. Crops are usually grown on raised bunds and banks or dams may be constructed to regulate water flow. Crops irrigated in this manner in Uganda include, cabbages, sweet potatoes and rice. Criticisms of surface irrigation methods focus on their lack of efficiency. As much as 40% of diverted water is thought to be lost along unlined irrigation channels (Plusquellec, 2002).

Sprinkler Irrigation Systems

Sprinkler irrigation is utilised on 5% of the world's irrigated lands (Kay, 2001). It is a technology which can be adapted to various soil and topographic conditions. In addition to this, pumps and pipes can be selected to give an even application at a controlled rate making it simple to use. Disadvantages of sprinkler irrigation systems include their lack of flexibility which can be a hindrance when one considers the variability in smallholder plot terrain, shape, size and use. They are not generally used in steeply sloping areas as they may encourage soil erosion. Sprinkler systems are sensitive to winds which can cause uneven water application. The initial economic outlay for a sprinkler irrigation system can also be high. In addition to this maintenance and supply of replacement parts is an important factor to consider as the system is dependent on their availability. Locally made low technology versions of sprinkler pumps are available.

Localised Irrigation Systems

In the 1990s drip irrigation accounted for 1% of irrigated crop land (Frausto, 2005). Drip irrigation consists of a series of pipes and emitters which deliver water to individual plants. Low head drip irrigation systems have been promoted widely in SSI. The system allows for individual smallholders to decide how much water to apply to their plants. Drip irrigation aims to maximise efficiency as water is only applied close to the plant. However, it has been shown that smallholders often over irrigate when using drip irrigation due to the ease with which water can be applied (Kay, 2001).

There are several disadvantages associated with drip irrigation. These include

- Emitter and lateral pipe blockages caused by silt, clay or sand and the build up of algae or chemical precipitation may occur (Kay, 2001). This may be due to neglecting to filter water before it enters the system (Carter, 1989). Kits such as those supplied by International Development Enterprise (IDE) have aimed to simplify drip kit design and minimise clogging by using micro tubes and providing pegs to keep them away from the soil as well as using simpler technology such as cloth filters. Nevertheless, this does not eliminate clogging difficulties entirely.
- Drip irrigation systems are not well suited to steeply sloping areas as uniformity of water application may be compromised. Although, it is possible to adapt application rates through use of pressure compensating emitters.

- Salinity can cause problems as salt builds up on the periphery of the wetted soil area (Savva and Frenken, 2002).
- Damage to drip lines may occur from rodents and small animals in search of water and via weeding (Practical Action, 2006).
- Water must still be conveyed to the low-head tank or bucket system. Smallholders may not see the direct advantage of pouring water into the system instead of directly onto the crop.
- A large amount of tubing is required for closely growing crops making it impractical (Savva and Frenken, 2002; Cornish and Brabben, 2001).

India is often viewed as a drip irrigation success story as they have seen uptake of drip irrigation systems rise in recent years. However, most private drip irrigation suppliers in India tend to focus on large hectare smallholders with high profit margins to whom it is easier to market the product (Frausto, 2005). In addition to this there are indications that smaller non-pump fed drip irrigation systems are not cost-effective and consequently uptake of these allegedly more smallholder-friendly systems has been limited (Kuelcho, 2003).

2.3 Smallholder Irrigation

Smallholder irrigation in Uganda

Smallholder irrigation in Uganda is often referred to as informal. This terminology reflects its emergence spontaneously and independent of any government or NGO initiatives and reflects a wide body of irrigation practice involving SWC techniques and swampland cultivation. However, Uganda has seen the development of formal government smallholder irrigation schemes in the 1960s (IPTRID, 1998). It was expected that these schemes would eventually be managed by smallholder co-operatives. However, management, financial and social problems all contributed to their abandonment (IPTRID, 1998).

Smallholders have practised irrigation in Uganda since the 1940s (IPTRID, 1998). Although there are a lack of formal irrigation schemes for smallholders the FAO estimates that informal smallholder irrigation has increased in Uganda (FAO, 2005). Swamps are currently the largest irrigation sources providing around 30 000 hectares of small-scale irrigation in the Tororo and Iganga districts which mainly cater for rice production (IPTRID, 1998). Smallholders may utilise the fringes of existing streams and swampland or apply water directly onto crops as in the case of potatoes or tomatoes. Streams and swamplands may be utilised to grow rice, sugarcane, potatoes, cabbages and other vegetables. Smallholders may also irrigate cash crops such as tomatoes or potatoes whose quality and subsequently price is affected by drought stress. This may be done by collecting water from an existing nearby source and manually transporting it to the crop during exceptionally dry weather. Additional support for smallholders utilising these methods of irrigation has been identified as beneficial if these systems are to be sustainable in the long term and avoid negative impacts on the local environment (TCP/UGA).

An FAO sponsored Special Programme for Food Security (SPFS) has been implemented in Uganda. However, there is currently little literature concerning its outcomes. There are plans for initial pilot studies on smallholder irrigation to be rolled out across 27 districts in 2008 and 2013 (Water for production sub-sector, 2003). Possibilities for water harvesting were explored along with institutional capacity building within the Ministry for Agriculture, Animal Industries and Fisheries (MAAIF) (IPTRID, 1998; TCP/UGA, 2000).

A pilot project involved construction of a night spring water harvesting and canal conveyance scheme for 6 ha of land. However, this has suffered from management difficulties which have meant the scheme is running behind time (IPTRID, 1998). Future plans in the area of SSI involve collaboration between National Agriculture Research Organisation (NARO) and MAAIF (IPTRID, 1998). There are also indications that National Agricultural Advisory Services (NAADS) will be involved in development of SSI in the future and a pilot scheme is currently being established.

The Water for Production sub-sector in Uganda acknowledges limitations to the development of irrigation for crops within the country. These include

- Inadequate technical capacity in irrigation and soil and water management at all levels
- Absence of mechanisms for assisting smallholders and smallholder groups in irrigation system development
- Insufficient coverage of SPFS (special programme for food security) programme in the promotion of small scale development including runoff/ rainwater harvesting (Water for production sub-sector, 2003).

Although, there are plans for districts to have dedicated soil and water management technicians this is not likely to be implemented until 2008 at the earliest.

Smallholder irrigation and Tea

The focus on large-scale irrigation within agriculture is reflected in attitudes towards tea production. Despite the fact that 20% of Uganda's tea comes from smallholders (Uganda Tea Development Agency Limited), tea is still perceived as a plantation crop and no studies have been conducted on the potential for irrigation at a smallholder level. Traditional estate irrigation systems for tea include sprinkler irrigation and drip irrigation systems. Kibena tea estate in Tanzania is another small-holder run co-operative which has introduced estate drip irrigation. Within Uganda, tea was irrigated in the past and the remains of piped sprinkler irrigation systems can be seen on some tea estates. However, few schemes are still in operation. In contrast, smallholder tea irrigation is untried. However, smallholder irrigation projects have been implemented for coffee bushes and home garden vegetables in Uganda with varying success. Therefore, there is potential for development of this technology.

Irrigation in the Wider Picture

"In the developing countries, the heads of the agencies concerned are usually engineers, but they often lack the knowledge of critically important non-technical factors such as the social structure of the smallholders to be benefited, economic constraints at local and national levels, and environmental issues"
(Kirpich in Plusquellec, 2002)

Recent reports have highlighted the lack of success of irrigation projects even going so far as to suggest that irrigation is "in a quiet crisis". Critique of irrigation schemes has highlighted many failures in the sector which have been attributed to technical, managerial and infrastructure constraints. There is increasing recognition that an irrigation project must account not only for the technical aspects of the scheme but the socio-economic also. Brown and Nooter (Brown and Nooter, 1992) summarised the common features of projects that were perceived to be successful thus;

- Simple low-cost technology. Usually small pumps drawing water from shallow aquifers, streams or rivers.
- Private and individual institutional arrangements.
- Access to inputs and markets for sale of surplus produce.
- High cash returns to smallholders when they are most needy.
- Smallholders are actively involved in project design and implementation.

Partly due to the criticisms levelled at past approaches to irrigation development there has been a shift in emphasis with large scale projects often eschewed in favour of small-scale projects. Smallholder irrigation projects have come to the fore in agricultural development activities over the past 20 years (Kay, 2001). Large irrigation initiatives which were commonplace in the 1970s and 1980s have largely been replaced with projects focusing on smallholder technology. However, the approaches to determining appropriate smallholder technologies for implementation in an area and even the definition of smallholder irrigation have been in flux. Greater recognition is now given to the contribution indigenous knowledge and skills can make to water management and irrigation strategies enabling development from current smallholder water management practices.

As smallholder resources are limited irrigation solutions must be low cost, easy to implement, technically simple and straightforward to maintain. Knowledge of the socio-economic context of smallholder livelihoods within the proposed project area is undoubtedly key to meeting the above criteria of success. Kay makes a useful distinction between modern and traditional irrigation technologies in his discussion of appropriate technology for sub-Saharan Africa (2001). Traditional technology includes surface irrigation, spate irrigation, swamp irrigation, hill irrigation, groundwater irrigation and flood plain irrigation. The term modern technology refers to methods such as sprinkler and drip irrigation which are relatively recent innovations. Kay suggests that the adoption of modern technology by smallholder smallholders can only occur when their farming has diversified beyond basic food crops (Kay, 2001). The poorest smallholders are unlikely to be able to adopt modern technologies as their primary concerns are food security and minimising risk (Kay, 2001). Building this observation into criteria for selection of water management technologies can be useful and is reflective of the strategies smallholders must employ in order to sustain a living.

It has been noted by several authors that irrigation is often presented as a panacea for food and crop supply difficulties (Kay, 2001; Faures, 2005). However, as several high profile large-scale irrigation projects have demonstrated, irrigation also has the potential to impact negatively upon smallholder livelihoods via unwanted socio-economic, health and environmental changes. In addition to this much irrigation technology is not technically or economically viable for smallholders. Within a sustainable livelihoods framework, it can be observed that smallholder livelihoods are affected by many different processes and agents which are integral to the sustainability of the agricultural system and any water management intervention.

Summary

SSI within Uganda is in its infancy with the building blocks for future research and developments in this area currently being put in place. This makes it an exciting time for the development of SSI in Uganda. SSI for tea is untried and its potential not known. As tea is traditionally estate irrigated only, there is no literature concerning smallholder irrigation of the crop. Nevertheless, the potential for SWC techniques clearly exists and there are a suite of SSI technologies which are available for consideration. A key consideration in assessing the possibility for implementation and adoption of SSI is the applicability of a technology to the social and physical environment.

3 Methodology

This chapter presents meteorological, soil, yield and sociological research methodology.

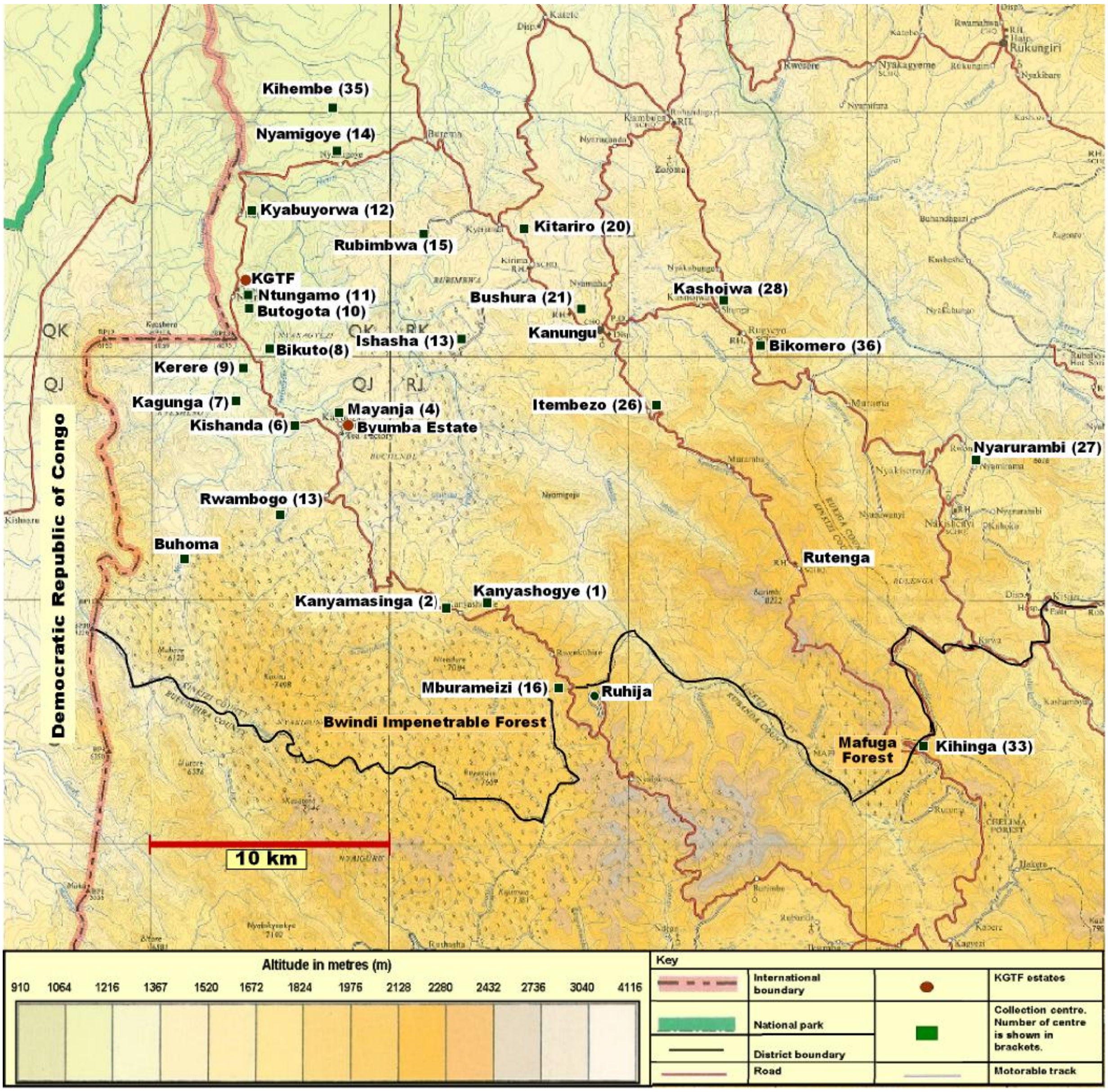


Figure 3. KGTF tea growing area altitudinal map. Collection centre numbers are listed in brackets. (Adapted from Government of Uganda, 1965)

Introduction

The terrain of the KGTF area is hilly with land varying in altitude from 1080m to 2080m. The district has an average annual rainfall of 1118 mm (Fountain, 2005). However, average annual rainfall within the study site between was 1409 mm (1997 – 2005). Sites for study were selected for a variety of reasons which included availability of climate data in areas close to Buhoma and KGTF, and specific logistical or socio-economic circumstances as was the case in Kihinga and Ruhija.

Details for a selection of sites in the KGTF area are presented in Table 2.

Table 2. Latitude, longitude and altitude of six sites within the KGTF area.

	KGTF	Rushamba	Buhoma	Ruhija	Rwambogo	Kihinga - Mafuga
Latitude	029 38 965	N/A	029 37045	029 40 549	029 40 982	029 50 290
Longitude	00 53 160	N/A	00 58 779	00 59 140	00 56 771	00 59 185
Altitude (m)	1080	1300	1300	2080	1325	1877

3.1 Climate

Temperature

Daily maximum and minimum and wet and dry bulb temperature data were recorded at Kayonza Growers Tea Factory (KGTF) at 9:00 am each day from 18th April to 28th August 2006. Wet and dry bulb temperatures were recorded using a whirling hygrometer. Climate data were also obtained for three additional sites: Ruhija (1987 – 2006), Buhoma (1992 – 2006) and Rushamba (1998 – 2006) from 1987, 1992 and 1998 until the present day respectively. These data were made available to the researcher courtesy of the Tropical Forest Research Centre (TFRC) based in Ruhija.

Rainfall

Daily rainfall data collected at the KGTF site by factory staff was available from January 1997 until August 2006. Rainfall data were collected using a metal rainfall gauge and plastic non-standardized collecting cylinder[9] at 9:00 am. The rainfall data collected was multiplied[10] by a factor of 1.57 by the climate data collectors at the factory. Rainfall data was also available for Ruhija (1987 – 2006), Buhoma (1992 – 2006) and Rushamba (1998 – 2006).

Double mass curve analysis

Double mass curves were created to compare KGTF rainfall data with the other rainfall collection centres in order to discover if data from one station had systematically changed from other stations (Brutsaert, 2005). Only days where recordings were available for each station were used for comparison. Rainfall data were also subjected to regression analysis in order to determine if there was a correlation between different rainfall collection stations.

Dependable rainfall

Dependable rainfall is that which on average over a long period of time can be expected to be met or exceeded. For this study an 80% probability of exceedance was used to calculate dependable rainfall for Kayonza rainfall data. In order for dependable rainfall to be calculated a normal distribution of annual total rainfall data for Kayonza was verified by homogeneity tests on the Rainbow programme (Center for Irrigation Engineering, 1990). However, homogeneity of the data was based on annual rainfall totals. Therefore, the test of homogeneity cannot assess whether the distribution of rainfall within a year follows a normal pattern.

In order to calculate crop water requirements dependable rainfall was calculated using KGTF rainfall data. Dependable rainfall (Pd) with 80% probability of exceedance was calculated according to the following method:

[9] The size of the collecting cylinder was 25cm in height with an internal diameter of 3.5cm. The measuring units were mm. It was not possible to find a rainfall collection cylinder of a similar specification.
[10] The rainfall collectors apply a factor of X1.57 on the advice of Ugandan meteorology department advisors. This factor is apparently applied in order to account for the non-standard size of the collection cylinder.

$Pd = \overline{P} - 0.84\sigma$ ……………………………….(Equation 2)

where $\overline{P}$ is mean annual rainfall and σ is standard deviation of annual rainfall. Monthly dependable rainfall was calculated using the following equation:

$P_{id} = P_{iav} \times P_d / \overline{P}$ ……………………………….(Equation 3)

where P_{id} is dependable precipitation in month i, P_{iav} is mean rainfall in month i and P_d is dependable annual rainfall (Doorenbos and Pruitt, 1984; Hess, 2006).

Effective rainfall

Not all rain which falls is able to be used by the crop as some of it may drain or be lost as runoff due to rainfall intensity or drainage losses (Hess, 2006). Therefore effective rainfall is that which is useful to the crop at the site where it falls (Dastane, 1978). Monthly effective rainfall was calculated within CROPWAT[11] (El-Askari, 1998) according to the USDA Soil Conservation Service Method which uses the following equations:

$P_{eff} = P (125 - 0.2 P)/125$ for P<250mm/month ……………….(Equation 4)

$P_{eff} = 125 + 0.1 P$ for P>250 mm/month ……………….(Equation 5)

Where P_{eff} is effective rainfall within a month and P is monthly rainfall.

ET_o (reference evapotranspiration)

Reference evapotranspiration is evapotranspiration from a hypothetical crop with complete ground cover under ideal conditions[12]. Monthly ET_o was calculated using monthly temperature, humidity, solar radiation and wind speed according to the FAO Penman Monteith method (Allen et al., 1998) within CROPWAT. This is a standard method for ET_o calculation (Allen et al., 1998). Data for all climate related calculations was taken from FAO Kabale data and Rushamba maximum and minimum temperatures

[11] CROPWAT Version 4.2 is a computer programme that calculates ET_o based on the FAO Penman Monteith method using monthly agroclimatological data.
[12] A hypothetical crop of 12 cm height with a fixed canopy resistance of 70 s m^{-1} and albedo of 0.23 Allen, R.G., Smith, M., 1994. An Update for the definition of reference evapotranspiration. ICID Bulletin 43, 1 - 35.

(FAO, 1984). Investigation of the sensitivity of ET_o data to temperature changes was undertaken by means of comparison between Kabale and Rushamba temperature data.

ET_c (crop evapotranspiration)

In order to obtain an evapotranspiration rate specific to tea a monthly ET_c value was calculated from ET_o data by multiplying ET_o by a crop coefficient (K_c) value.

$ET_c = K_c \times ET_o$ ……………………………….(Equation 6)

The crop coefficient value is applied to take into account crop characteristics. Values ranging from 0.85 to 1 can be used (Stephens and Carr, 1991). The value of 0.85 as the K_c value relative to pan evaporation has been identified in a range of experiments (Blackie, 1979, Willatt, 1973, Laycock and Wood, 1963 in Carr and Stephens, 1992). However, both values are commonly applied to tea. For the purposes of these calculations a value of 1 was used. As tea is a perennial crop usually harvested when mature, the K_c value is constant. For other crops this value changes according to growth stages. However, ET_c reflects evapotranspiration from disease-free, adequately fertilized crops grown in optimal soil water conditions in large fields (Allen et al., 1998). ET_c can be calculated using an adjusted K_s value to take into account evapotranspiration changes due to scanty plant growth, disease and pest presence or impenetrable soils (Allen et al., 1998).

$ET_{c\ adj}$

ET_c was adjusted in order to account for water stress. This was done by multiplying ET_c by a daily crop stress coefficient (K_s).

$ET_{c\ adj} = ET_c \times K_s$ ……………………………….(Equation 7)

The K_s value was calculated on a cumulative basis using the soil water deficit model constructed. The model started with a crop stress (K_s) value of 1 which is a value for mature tea assuming full crop cover on a plot (Allen et al., 1998).

Saturation Vapour Pressure Deficit (SVPD)

SVPD was calculated for the KGTF site using daily wet and dry bulb and maximum and minimum temperatures. Wet and dry bulb temperatures were recorded using a whirling hygrometer during the research period. The following calculations were used including a correction factor for a whirling hygrometer:

$es = 0.6108 \cdot \mathrm{EXP}\,[17.27 \cdot Tdry/(Tdry + 237.3)]$ …………(Equation 8)

$e^o(Twet) = 0.6108 \cdot \mathrm{EXP}\,[17.27 \cdot Twet/(Twet + 237.3)]$ …………(Equation 9)

$ea = e^o(Twet) - 0.000662 \cdot 101 \cdot (Tdry - Twet)$ ………...(Equation 10)

where *es* is saturation vapour pressure at dry bulb temperature (*Tdry*), $e^o(Twet)$ is saturation vapour pressure at wet bulb temperature (*Twet*) and *ea* is actual vapour pressure (Allen et al., 1998).Therefore saturation vapour pressure deficit was calculated thus *es* – *ea*.

Humidity

Humidity was calculated for the KGTF site during the research period from wet and dry bulb temperatures using the above SVPD equations where relative humidity is *ea*/*es*. Additional humidity data was available for the Ruhija, Buhoma and Rushamba sites. However, as with the rainfall data this was sporadically collected and so data was incomplete in places.

Other climatic observations

Anecdotal evidence on climate was collected and observations of localised climatic events such as hailstorms were recorded.

3.2 Soil

Available soil data concerning the KGTF area and district were collected. A soil feel test was also conducted on the top 20 cm of soil at each smallholder plot visited.

Modelling potential soil water deficit (SWD)

The SWD can be defined as the difference between the present water content and the field water capacity content. Potential soil water deficit was modelled using the following equation (Nixon et al., 2001):

$\text{Potential SWD}_i = \text{Potential SWD}_{(i-1)} + ET_{c\,i} + D_i - R_i - I_i.$ …………(Equation 11)

Where D is drainage on day i, R is rainfall on day i and I is irrigation on day i. Soil is assumed to drain if rainfall occurs when the soil is at field capacity. As the crop is not under irrigation this was not included in calculations for the model created. ET_o values calculated in CROPWAT as previously described were used for the basis of modelling (FAO, 1984). Scenarios for different soil and rainfall patterns in the KGTF area were modelled.

Values for total available water (TAW) in mm per metre for different soil types were taken from Hudson (1975). However, other values could have been used (Table 3). Readily available water (RAW) was calculated using the following equation;

p x TAW

where p is depletion fraction assumed to be 0.4 (Allen et al., 1998). This represents the fraction of the total available soil water which can be used by the crop without negative impact upon evaopotranspiration and growth (Doorenbos and Pruitt, 1984).

Table 3. Comparison of two different soil type values from different sources for TAW and RAW.

Source	Soil type (	Clay Loam	Sandy Loam
(Hudson, 1975)	TAW (mm/m)	200	100
	RAW (mm/m)	80	40
(Doorenbos and Pruitt, 1984)	TAW (mm/m)	180	130
	RAW (mm/m)	72	52
Depletion fraction (p)		0.4	0.4

The depletion fraction can also be adjusted for ET_c rate with the following equation:

$p = p$ (from FAO 56) + 0.04 (5 - ET_c) …………………………….(Equation 12)

where p is $0.1 \leq p \leq 0.8$ and ET_c is in mm/day (Allen et al., 1998). However, this was not calculated for the model. Values for RAW specific to the soil type and tea crop at KGTF were calculated using the following equation;

p x TAW x d ………………………………….(Equation 13)

where p is depletion fraction, TAW is total available water and d is root depth. The root depth used in these calculations was 1.05 m based on three soil pits dug alongside tea bushes to measure tap root depth on the KGTF estate at Butogota. However, as mentioned in the literature review other researchers have found roots 5 and 6 times this depth (Stephens and Carr, 1991). Nevertheless, maximum root depths of 1.5 m are listed for tea (Allen et al., 1998).

Modelling actual soil water deficit (SWD)

In order to model actual soil water deficits the same equation as previously described was used with $ET_{c\ adj}$ replacing ET_c as follows:

$SWD_i = SWD_{i-1} + ET_{c\ adj} + D_i - R_i - I_i$. …………………………..(Equation 14)

Estimating crop requirements

CROPWAT was used to estimate crop requirements for different rainfall and temperature patterns.

Discussion

The climate data collected were subject to some limitations which can be summarised as follows:

Collection methods

Climate data at each site was not collected by the same individual which may mean there are discrepancies caused by human error in the readings obtained. Some rainfall data had also been converted from inches to millimetre readings leading to possible inconsistencies in the amounts recorded. Temperatures were recorded at KGTF using a maximum and minimum thermometer which was positioned under the shade of a tree approximately 2 m from the ground. However, it is likely that the thermometer was exposed to direct sunlight during the day leading to elevated recordings. In addition to this GPS readings were found to be potentially inaccurate when compared with latitude and longitude from a world map.

Continuity of data

Data collected for Ruhija, Buhoma and Rushamba was not continuously recorded and so no complete climate records are available. Rainfall data for KGTF was continuously recorded from 1996. However, temperature and humidity data for KGTF was not available for the same period of time. Therefore, data from corresponding dates at other sites was used in modelling where available.

3.3 Yield

Collection of data

Monthly individual smallholder yield data from 1996 until 2005 was obtained from a Microsoft®Access database at KGTF. This was available for 4618 smallholders. It contains individual farmer identification number, area of tea (ha) and monthly green leaf production (kg) from 1995 until 2006. The data from 1996 until 2005 were exported into five Microsoft®Excel worksheets. As 1995 and 2006 were incomplete years they were excluded from further analysis. Mean annual monthly yield totals across each smallholder's total production were calculated. Individuals without recent green leaf production figures were excluded from the study along with those who had zero production in an average month in order to exclude those who had ceased production. As 4072 smallholders are listed by the factory as currently supplying green leaf not all smallholders listed on the database are currently involved in tea production.

Investigation of KGTF area yield

The mean monthly production totals for each smallholder's green leaf were used to calculate the mean proportion of annual green leaf received in each month. A standard deviation value was also calculated to identify records with yields that had the highest variability in proportion of leaf received each month for a mean year. Yield variability was calculated for all 36 collection centre areas in the KGTF area over the course of ten years.

Estimating potential yields

Potential yield in the absence of drought and with drought stress was calculated using the radiation efficiency approach according to (Carr and Stephens, 1992; Doorenbos and Kassam, 1979) using the data shown in Table 4. Monthly climate data was used for calculations. Mean rainfall data from KGTF was used. ETo values were taken from Kabale data. An LAI of 6 was used, taken from 3 year old clone tea buses from Ng'etich & Stephens (2001). *fs* (proportion of solar radiation intercepted by the canopy) was calculated to be 0.99 using the following equation:

$$fs = 1 - e^{-k \times LAI}. \qquad \text{(Equation 15)}$$

which assumes a full canopy cover for tea and a light extinction coefficient (k) of 0.6 and a LAI of 6. Ks values are taken from the SMD model created for clay loam soil.

Table 4 Monthly climate parameters used for potential yield calculations

Month	**Days**	**ET_o mm**	**ET_c mm**	**Solar. Radiation $MJ/m^{-2}/d^{-1}$**	**Leaf area index (LAI).**	***fs***	***S.fs* MJ/m^{-2}**	**Ks**	**$ET_{C\ adj}$.**	**Rainfall mm**	**$ET_{C\ adj.}$ - Rainfall mm**
J	31	102.3	102.3	16.2	6	0.97	487	0.92	94.4	60.6	34
F	28	98.0	98.0	18.0	6	0.97	489	0.73	71.1	54.5	17
M	31	102.3	102.3	17.2	6	0.97	517	0.85	86.8	112.9	-26
A	30	87.0	87.0	15.7	6	0.97	457	0.95	83.1	152.3	-69
M	31	83.7	83.7	14.0	6	0.97	421	1.00	83.7	111.4	-28
J	30	90.0	90.0	16.3	6	0.97	474	0.97	87.3	55.5	32
J	31	102.3	102.3	16.2	6	0.97	487	0.78	79.7	48.0	32
A	31	102.3	102.3	16.0	6	0.97	481	0.84	86.1	112.8	-27
S	31	105.4	105.4	17.3	6	0.97	520	0.99	104.5	207.3	-103
O	31	102.3	102.3	17.2	6	0.97	517	1.00	102.3	232.2	-130
N	30	93.0	93.0	15.9	6	0.97	463	1.00	93.0	156.4	-63
D	31	93.0	93.0	15.4	6	0.97	463	1.00	92.8	104.7	-12
Total		1161.6	1161.6				5777		1064.8	1408.7	

$Et_{c\ adj}$ is taken from the SMD calculations as monthly averages (1996 – 2005). These values were used in the following equation:

Potential yield (g m^{-2}) = *S. fs* . ε_S . HI ……………..…………….(Equation 16)

Where *S.* is solar radiation (MJ m^{-2}), f_S is the proportion of that radiation intercepted by the canopy of the crop, ε_S is the radiation use efficiency (g MJ^{-1}) and *HI* is the harvest index (the proportion of total dry matter that constitutes yield). Potential yield under drought stress was estimated by adapting the previous calculation (Doorenbos and Kassam, 1979):

Actual yield = Potential yield x $ET_{c\ adj}/ET_c$ ……………………..………(Equation 17)

Where ET_c is ET_o x Kc value (1) and $ET_{c\ adj}$ is ET_c x K_s.

3.4 Sociological context

Approach

A total of 40 stakeholders were interviewed during the course of this study. These included smallholders, KGTF management, local NGO workers, UTDA staff, staff at Igara tea factory, local and national government officials and staff at national organisations such as NAADS. Some of the interviews were undertaken in English but the majority of interviews with smallholders were conducted in the local Rukiga language with the help of a translator. American association of anthropology ethical guidelines were followed and verbal consent obtained from all informants. All informants were given the opportunity to remain anonymous. Smallholder names have been changed to protect the identities of some participants in the study.

Sampling

Smallholders were identified and interviewed with the help of KGTF area field officers during the initial phase of research. Some smallholders were interviewed by prior arrangement while others were identified and approached at random. Once yield data had been obtained smallholders were also identified for interview based on their standard deviation ranking for mean annual monthly proportion of green leaf received by the factory (1997 – 2005) and collection centre area of residence. A selection of smallholders were chosen from yield data results, from smallholders approached during the initial interviews and from areas ranked by field officers according to drought stress. Smallholders with no production in a given month were excluded from the study in order to minimise the likelihood of picking smallholders who were no longer producing and to focus on those whose shambas were in continual production.

Tea collection sheds were frequently used as in initial point of contact for smallholders. However, visits to smallholder’s land and homes were undertaken subsequent to this when possible. All field officer areas of the KGTF were visited at least once in order to obtain an overview of the diverse social and geographical terrain. Interviews were mainly conducted in the afternoon as it was recognised that this is when smallholders are likely to have time available. Interviews were undertaken at a variety of locations including the smallholder fields, shambas, homes and businesses.

Theoretical background

Research techniques drew upon a modified agroforestry Diagnosis and Design (D & D) approach integrated into a grounded theory framework. D & D was used as an initial framework for information gathering while grounded theory served as a tool for development of topics, theme identification and analysis of data collected. Farming system observation methods and questioning and a review of natural resources were combined with a combination of structured and semi-structured questions which allowed for an informal exploration of the topic within a flexible framework.

Table 5. Modified first three stages in the D & D approach. Modified from Raintree, 1987

Stages	Steps
1. Prediagnostic	Planning the study
	Regional reconnaissance
	Preliminary description of land use systems
	Selection of the sites for further analysis
2. Diagnostic	Diagnostic interviews using grounded theory structure and analysis framework.
	Diagnostic analysis
	Specifications for appropriate interventions
3. Design	Identify candidate technologies
	Technology specifications
	Synthesis of technology possibilities in light of SLF.

Information was collected on the following topics:

- Land and Land use history
- Farm Resources
- Farming System
- Livestock
- Water
- Labour

- Cash Sub-system
- Savings and Investment

Troubleshooting was undertaken in order to identify constraints in the farming system and any potential or current problems. For example, the tea subsystem was explored in order to ascertain how tea supports smallholder livelihoods and any potential or current problems smallholders perceive in tea production.

A list of sample questions modified from Diagnosis and Design methodology (Appendix 2) were used as starting points. Research evolved within an overarching grounded theory framework for collection and analysis of data (Box 4).

Box 4. Grounded Theory

"Understanding is achieved by encouraging people to describe their world in their own terms"(Rubin and Rubin, 1995)

Grounded theory is a qualitative research methodology which encompasses both data collection and analysis. The main aim of qualitative interviewing is to discover what others feel and think about their world. Grounded theory interview techniques aim to enable an environment in which both interviewee and interviewer can lead the conversation and in which the interviewer is sympathetic to the conversational partner and self-aware. Grounded theory can be seen as an extension of ethnographic approaches to investigation of culture which aim to obtain 'thick desccription' of cultural behaviour (Geertz, 1973). Therefore, deciphering the symbolic content of information obtained is equally important to obtaining verifiable facts regarding a topic. Qualitative interviewing design within this framework is flexible, iterative and continuous in that it is a continuously evolving process as new topics for exploration emerge.

Analysis within the framework is also a continous process. Identifying concepts and themes specific to the research topic is part of this. Interviews are coded to group responses into categories that bring together similar ideas, concepts or themes. These are refined during the course of research and help to build up overarching themes within the research.

Cash Sub-system

Farm budgets were drawn up in conjunction with 4 smallholders selected as case-studies for this research. These aimed to list all expenses and income to the household during the period of one year. This enabled investigation of smallholder incomes in order to ascertain what proportion of the cash Sub-system tea production accounts for and the ways in which smallholders prioritise and manage expenses.

Supporting Information

Technological assessment was intertwined with both natural science investigation and social science methodology as data concerning climate and social factors influencing water use had an impact upon assessment of appropriate technologies for consideration.

Box 5. Irrigation requirements for tea

Monthly irrigation requirements and gross irrigation requirements for tea were estimated using the following methods. Rainfall data from the KGTF area using the following equations from (Doorenbos and Pruitt, 1984).

$In = ET_{c\ adj} – P_{eff}\ (dep)$

Where In is net irrigation requirement, ET_c is crop evapotranspiration and P_{eff} (dep) is effective dependable rainfall. A dry season was defined as 2 to 3 months using climate data. Mean data from 1997 to 2005 was used to estimate a mean P_{eff} (dep) of 87 mm during June and July. The mean monthly $ET_{c\ adj}$ requirement was calculated to be 215 mm during this period. Therefore, the net irrigation requirement (In) for June and July was calculated to be 128 mm. During the January and February dry season In was calculated to be 124 mm. Annual Net In amount using the above calculations is 252 mm for tea which translates as 2008 m^3 for 0.4 ha. Using CROPWAT annual net In for tea was calculated to be 255 mm.

Gross irrigation requirement were calculated thus:

$Vi = A \times In \times 10/Ep$

Where Vi is Volume of water required for period i, A is area in ha, In is net irrigation requirement for the period, 10 converts from mm to m^3 and Ep is irrigation efficiency of the system. A hypothetical efficiency of 50 % is assumed for initial calculations as this represents an average efficiency for a system. Efficiency will be higher or lower depending on the system water losses. An initial area of 0.4 ha or ½ acre was used for calculations. Therefore, dry season irrigation requirements for 0.4 ha of tea are approximately 1024 m^3. Irrigation requirements for other crops were calculated using CROPWAT with a 50% Ep.

Irrigation requirements

Irrigation requirements for tea were calculated (Box 5). The water requirements influenced the type of technologies that could be considered for irrigation of tea and other household crops.

Maps

Maps of the KGTF area were obtained. However, as the district has been demarcated recently a Kanungu district map was unavailable. It was possible to obtain a Rukungiri district map which covers some of the area. However, as KGTF also collects green leaf from areas bordering Kabale district an official map was not sufficient. A tourist map was also collected although topographic details on this were lacking.

Diagrams

Diagrams were drawn in order to record smallholder plot details and to cross-reference with smallholders and their families details of land use, geography and farm layout. Elements which could affect potential technologies and uptake were also recorded.

Observations

Observations on aspects relevant to potential technologies were collected. This included collecting information with a view to ascertaining which technologies may or may not be appropriate for smallholders and the environmental context. Data on the following topics was collected:

- Water resources
- Topography
- Soils
- Type of crops grown
- Cost of labour
- Availability of materials
- Energy requirements

Feasibility

Feasibility assessment involved both technical and social investigation. The main areas of investigation for this were (Appendix 3) (Underhill, 1990):

- What is the potential impact on household structure?
- How do children's education needs affect labour?
- How do people eat and how adequate is their diet?
- How do weather, conflict and access to inputs affect farming now, in the past and potentially in the future?
- What is the potential impact on production activities?
- Are the needs of smallholders being met?
- What impact would production have on these?

- What change in income is likely?
- Is the proposed intervention necessary?
- Would water be better used elsewhere?
- Are there other developments which should be prioritised over or combined with irrigation supply? E.g. domestic water.
- What is the smallholder skills base?
- What is the smallholder motivation for irrigation?

General constraints to social study

Geography. The distances between different research sites and communities within the KGTF area meant that travel time and constraints had to be taken into consideration when planning visits. Heavy rains could prevent travel to certain areas. In addition to this the factory has a limited number of vehicles and so travel was not always possible.

Timing. The time at which interviews were sought and undertaken affected the success in finding a specific smallholder and the time he had available to talk. For example, leaf collection days proved to be good times to find smallholders and interview them as they waited for leaf collection. Conversely, in the morning smallholders were often busy plucking leaf or tending to other farm responsibilities.

General limitations and considerations

Problems with the social aspect of the study included the linguistic difficulties associated with translating conversations. In the Rukiga language the word for drought 'omushana' is the same word used to describe sunny weather and the dry season. In addition to this the word for irrigation means to spray water onto something. As this study takes a broader definition of irrigation further exploration of respondent's answers was often necessary. However, it is acknowledged that translation of terms may have led to misunderstandings and that there may be other problems with terminology that were unidentified by the researcher.

Accuracy of data was verified by triangulation. Repeat interviews and cross-checking answers among several smallholders helped to highlight discrepancies in data obtained. However, it is acknowledged that this may not have highlighted all errors in the data. Many households were reluctant to admit to alcohol and tobacco consumption let alone estimate the cost of this. Anecdotal evidence and health statistics for the district suggest that their use is very widespread. In addition to this, respondents were understandably reticent to discuss income from activities not condoned by the factory or that the respondent felt I might not condone such as illicit leaf diversion, acting as a leaf buying agent smuggling goods or brewing of alcohol. Many smallholders were also happier conceiving of monthly expenses over annual ones perhaps as debts and income are often balanced in line with monthly tea payments. Phrasing of questions was modified to suit this.

Limitations to Methodology

Lack of Participant Observation. As sites were some distance away and the focus was on attempting to summarise the breadth of smallholder contexts little participant observation was undertaken with individual smallholders.

Sampling technique not representative. The sampling technique was not designed to be representative of all 4072 currently producing smallholders. However, this means that the results cannot be viewed as statistically representative of the whole KGTF area. This study focuses primarily on smallholders with 0.45 ha or less tea production area.

4 Results and analysis

This chapter introduces meteorological, soil and yield data concerning the study site.

4.1 Climate

Temperature

Mean monthly temperatures (2000 – 2003) at three sites within the KGTF area do not vary by more than 3 degrees from month to month (Figure 1). However, there are geographical differences between mean temperatures which are likely to be an effect of altitude. In general, for each 100 m increase in altitude temperature decreases by 0.6 ˚C (Carr and Stephens, 1992). Ruhija at an altitude of 2080 m had a mean temperature of 16.3°C, whereas Rushamba at an altitude of 1300 m had a mean temperature of 21.1°C. Temperature data from the nearest official collection point in neighbouring Kabale district which is at an altitude of 1860 m is similar to that at Ruhija. However, this data was obtained from FAO figures from 1987 and anecdotal evidence suggests that temperatures have increased in the area. Kabale temperatures may be cooler than Kayonza as the town is located close to a lake.

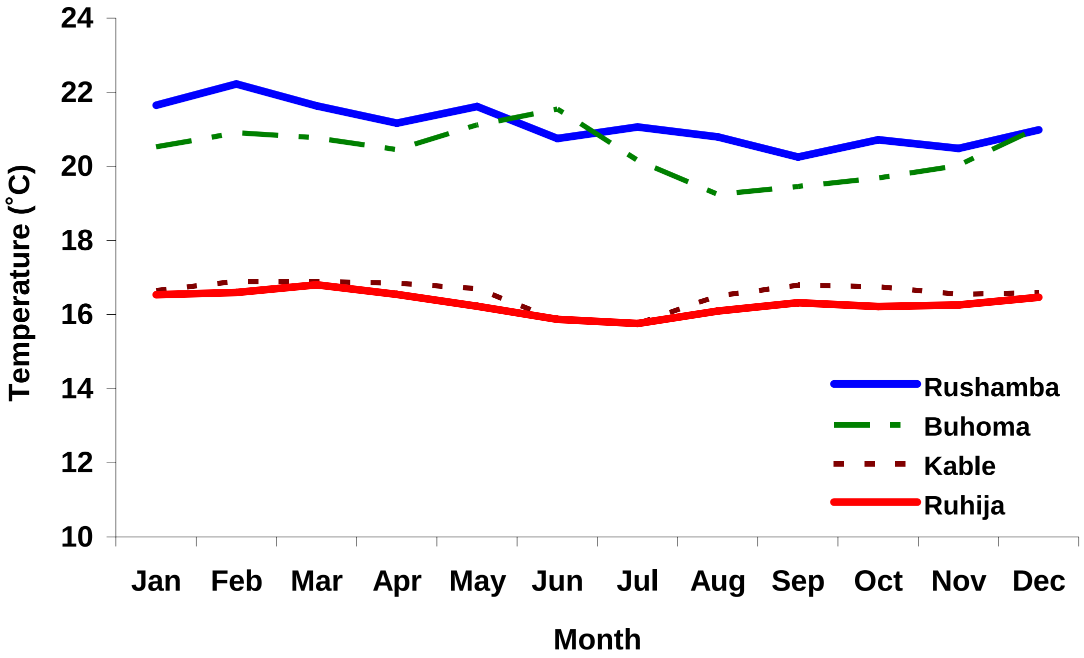


Figure 4. Mean monthly temperatures for Ruhija, Rushamba and Buhoma within the KGTF tea growing area (1997 – 2005) and for Kabale town (FAO, 1984).

Rainfall

Spatial variation

Mean annual rainfall appears to vary geographically. Ruhija (alt.:2080 m) had a recorded mean rainfall of 1025 mm (1999 – 2005), lower than that at KGTF (alt.:1080 m) which was 1416 mm for the corresponding period. Mean rainfall at Rushamba (alt.: 1300 m) during this period was 1463 mm. Rainfall data for Buhoma was not available for 8 months during the corresponding period. However, excluding the missing months mean annual rainfall recorded was 1600 mm. As we might expect higher rainfall patterns at higher altitudes recordings for Ruhija and Rushamba were unexpected. In addition to this anecdotal evidence from smallholders and field officers in the area suggests that there is greater rainfall at Ruhija than at KGTF.

Temporal variation

Annual total rainfall varies according to rainfall collection centre (Figure 5).

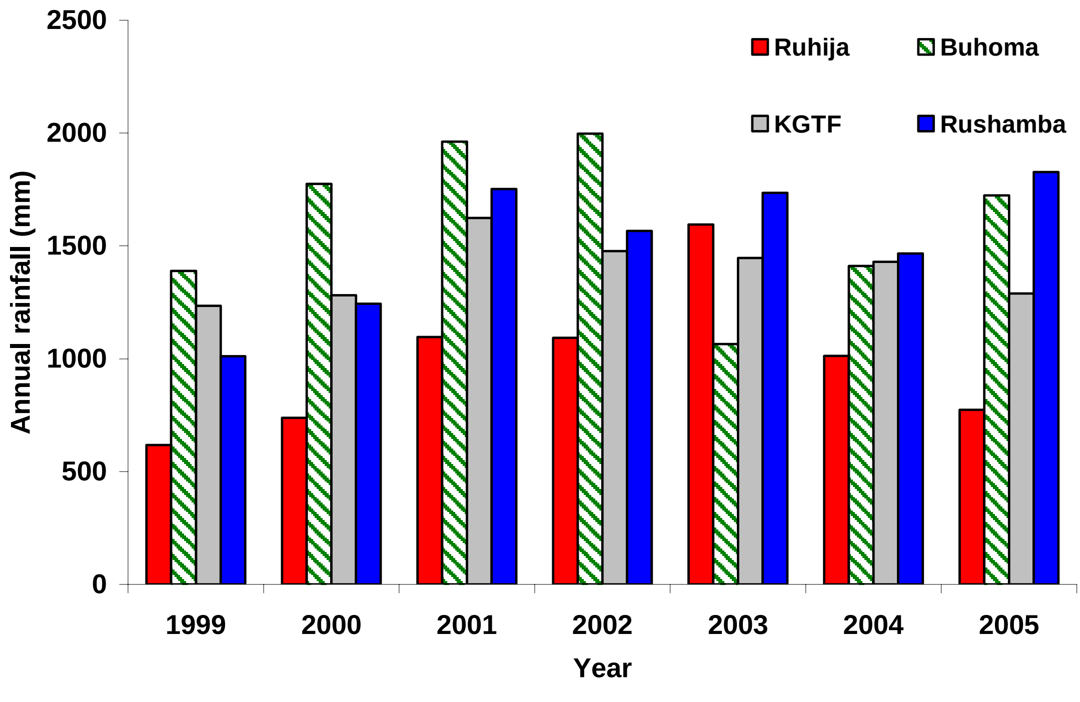


Figure 5 Annual rainfall totals 1999 – 2005 Ruhija, Buhoma, KGTF and Rushamba.

Annual total rainfall figures for Ruhija are lower than KGTF for all years except 2003 which is unexpected as Ruhija is located at a higher altitude than KGTF. Buhoma rainfall appears to be consistently higher than KGTF in all years apart from 2004 when KGTF, Buhoma and Rushamba all record similar total annual rainfall.

Although the annual rainfall recorded at Ruhija was less the mean monthly rainfall distribution follows the same bi-modal pattern with two distinct peaks within each wet season (Figure 6). Mean data suggests that the second rainy season from September to November is the wettest in the year with approximately a third more rain falling in this period than the first wet season from March to May. Buhoma mean rainfall in this period is double that of the first wet season. This is supported by anecdotal evidence from smallholders such as Geoffrey Mutuma who told me that *"we usually plant in March and September but the September season is best because it has more rain than the March season"*[13]

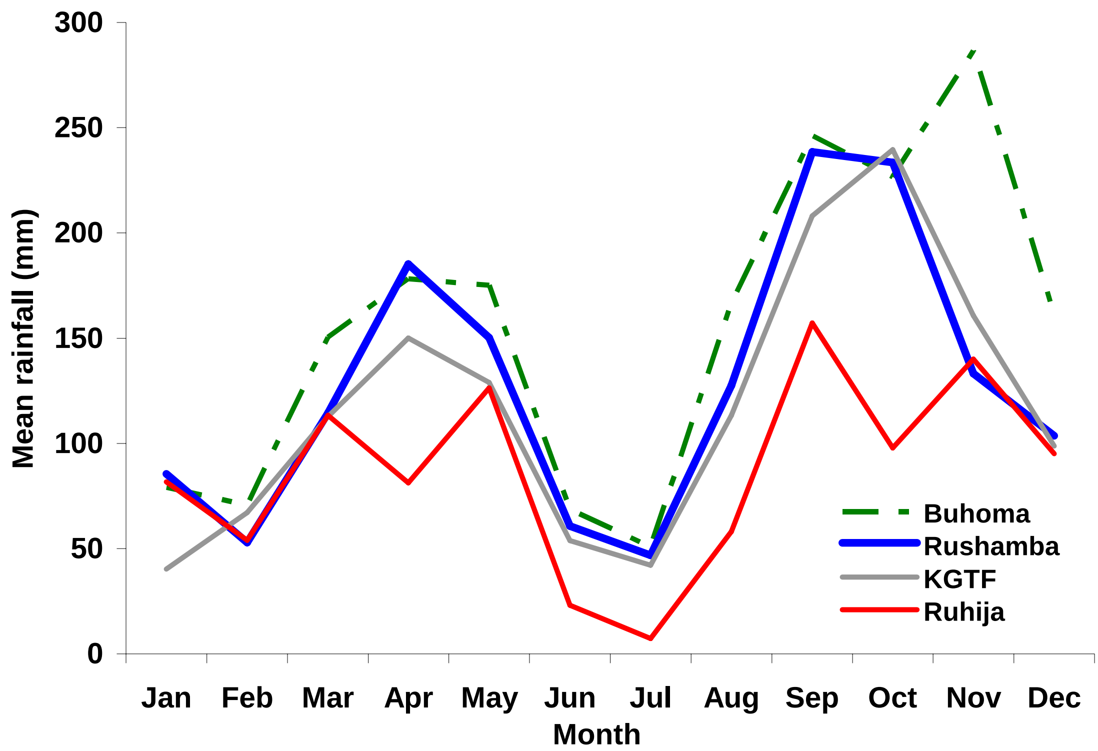


Figure 6. Average monthly rainfall for KGTF, Rushamba and Ruhija (1999 – 2004) and Buhoma (2000 – 2004)

[13] June 23 2006. Geoffrey Mutuma. Re: Farming regime.

Intra-site variation

Annual and monthly rainfall can vary at a given site. For KGTF, 1999 was the driest year in terms of total annual rainfall while 2001 had the highest total annual rainfall. When compared with the mean year (1999 to 2005) the variability in rainfall totals can be observed (Although there is little rainfall in July of 1999 rainfall in August 1999 (205 mm) is almost double that of the mean year (112 mm). 50 % of mean annual rainfall (1997 – 2005) falls between September and December (with proportion ranging from 43% to 56% in each year). In the months of May to August this percentage is 27% (with proportion ranging from 15 % to 26 %) (Figure 7).

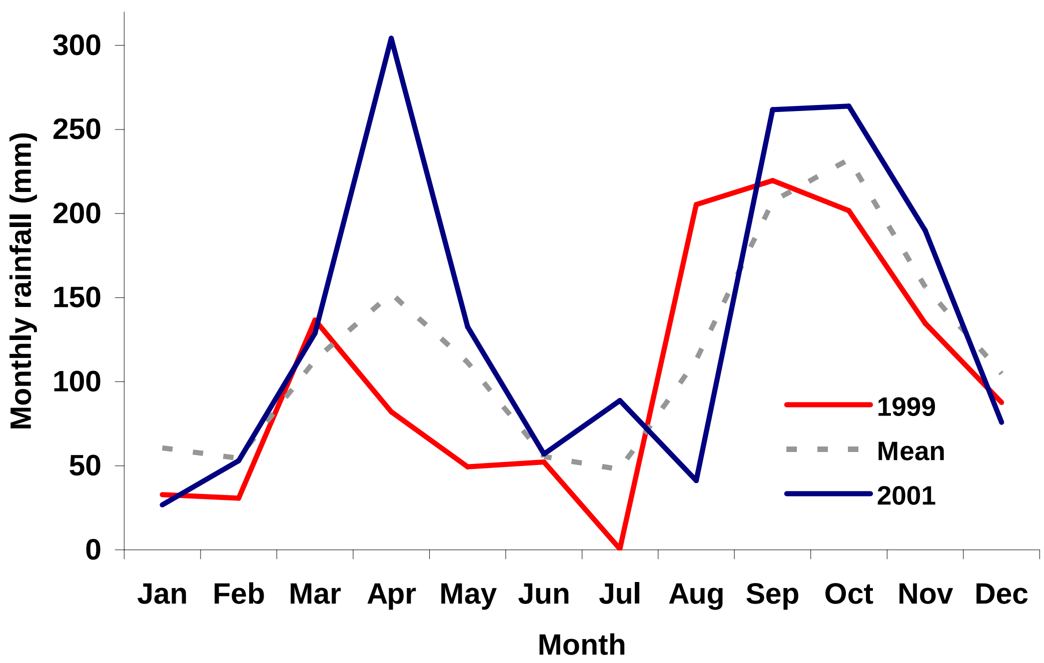


Figure 7 Monthly rainfall at KGTF in 1999, 2001 and mean (1997 – 2005).

Double mass curve analysis

Double mass curve analysis was undertaken to ascertain if each rainfall station followed a similar measuring pattern and to determine if a systematic change in measuring conditions had occurred. Individual cumulative rainfall data were plotted against the mean cumulative rainfall data for all sites. This showed two distinct patterns in rainfall, between Buhoma and Rushamba whose rainfall appears to have increased and Kayonza and Ruhija whose rainfall appears to have decreased during the period Figure 8. A dip in the Kayonza rainfall record can be seen suggesting a change in how measurements were taken in around 2002. This could be a result of measuring changes or changes in climate. If data from 1st January 2003 is plotted, the relationship between rainfall at each location is clearer (Figure 9).

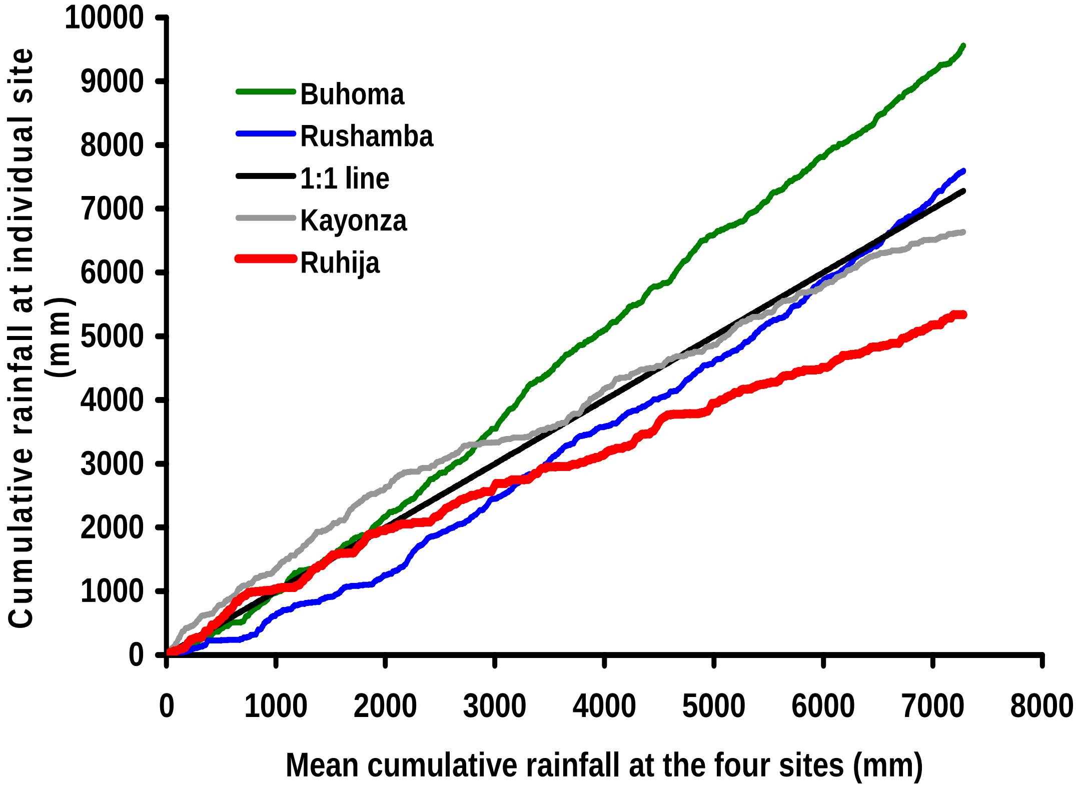


Figure 8. Mean cumulative rainfall at each individual site plotted against mean cumulative rainfall for all sites (1997 – 2005).

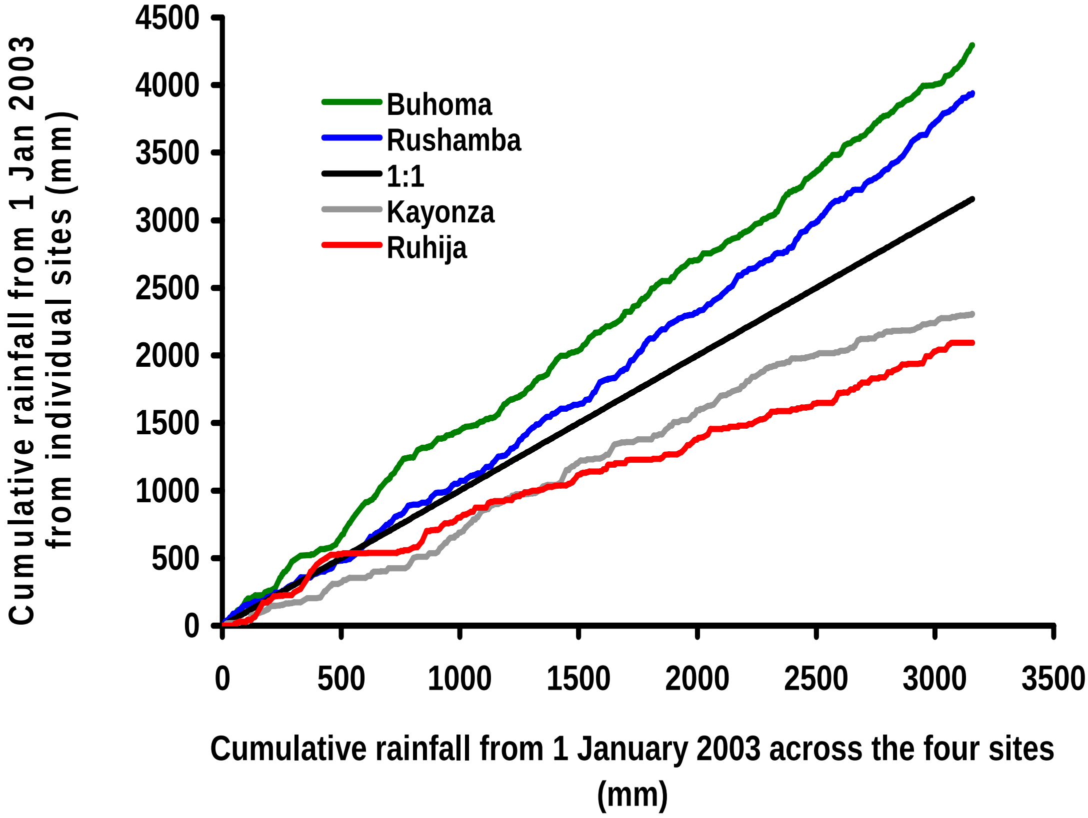


Figure 9 Combined mean cumulative rainfall for Rushamba, Ruhija and Buhoma plotted against KGTF cumulative rainfall (1997 – 2005)

Rainfall correlations

Regression analysis was performed on monthly rainfall data in order to determine if there was a correlation between sites. This revealed potential inaccuracies in the data. For example, when rainfall data from KGTF and Ruhija was analysed no correlation was found. However, a large number of zero readings existed in the raw data for Ruhija possibly as a result of zeros being recorded when a collection was not taken or readings being recorded in inches instead of millimetres. Omitting zero readings for Ruhija gave a better correlation (adjusted R^2 = 0.6 as shown in appendix 3). However, this was based on a limited number of recordings (Figure 10).

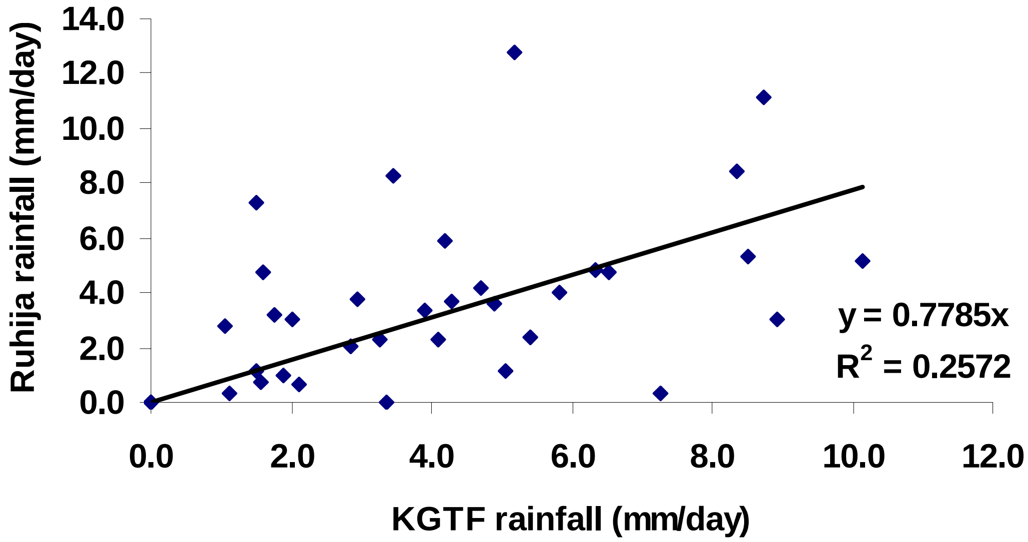


Figure 10 KGTF and Ruhija rainfall omitting zero recordings.

A correlation was determined between Buhoma and KGTF data (adjusted R^2 = 0.8 as shown in appendix 3) as shown in Figure 11.

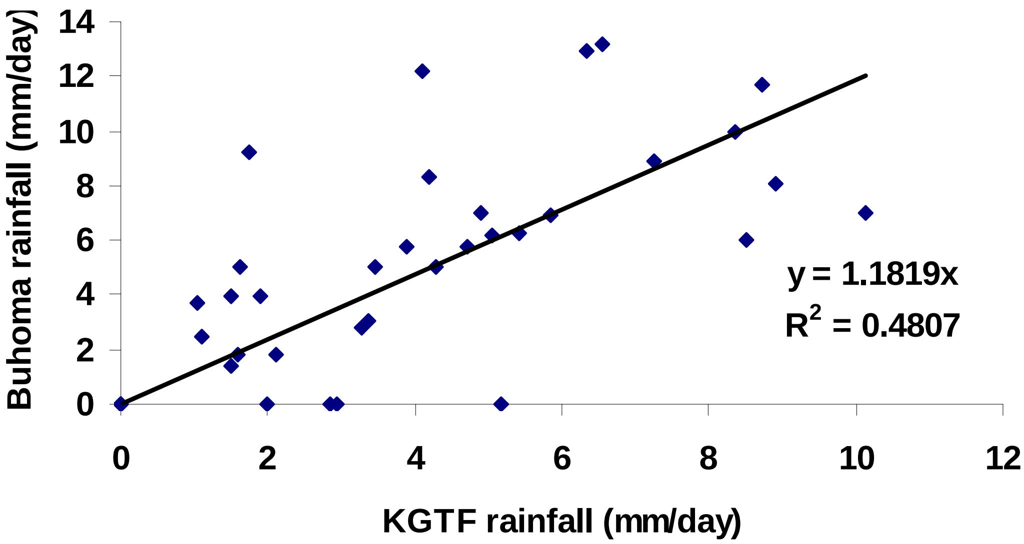


Figure 11. Kayonza and Buhoma rainfall correlation.

Buhoma's close proximity to Bwindi forest may contribute to the increased rainfall at this station in comparison to KGTF. No other correlations were observed between rainfall collection sites. Additional statistical analysis can be found in appendix 3.

A rainfall scenario of an 18% increase in rainfall was calculated and used to model potential SWD at similar altitudes and locations.

Reference Evapotranspiration (ET_o)

ET_o figures calculated for Kabale and the KGTF area were compared. Kabale temperature and ET_o data were taken from FAO data (FAO, 1984). ET_o for the KGTF area was calculated in CROPWAT (according to the FAO Penman-Monteith method) using temperature data from Rushamba. All other parameters were taken from FAO Kabale data. Table 6 shows the difference between ET_o values obtained when maximum and minimum temperatures vary. These differences affect calculation of ET_c and $ET_{c\ adj}$ and subsequent irrigation requirements.

Table 6. Comparison of mean monthly temperature and ET_o (FAO Penman Monteith Method) data for Kabale and Rushamba

Month	Rushamba Min. Temperature (˚C)	Rushamba Max. Temperature (˚C)	Rushamba Et_o (mm $^{-1}$)	Kabale Min. Temperature (˚C)	Kabale Max. Temperature (˚C)	Kabale ET_o (mm $^{-1}$)
JAN	21.6	28.8	3.6	9.6	23.7	3.3
FEB	22.2	30.4	4.0	10.0	23.8	3.5
MAR	21.5	28.9	3.7	10.3	23.5	3.3
APR	21.3	28.2	3.3	11.1	22.6	2.9
MAY	21.7	28.7	3.0	11.2	22.2	2.7
JUN	20.7	28.4	3.4	9.2	22.5	3.0
JUL	21.1	29.1	3.7	8.5	23.0	3.3
AUG	20.8	27.6	3.6	9.7	23.3	3.3
SEP	20.3	26.9	3.6	10.0	23.6	3.4
OCT	20.3	26.4	3.5	10.3	23.2	3.3
NOV	20.0	26.0	3.2	10.3	22.8	3.1
DEC	20.7	27.2	3.2	10.1	23.1	3.0

ET_o values obtained using Rushamba temperatures were used in all calculations as they were deemed to be more representative of the KGTF area. As Kabale values were taken from a 20 year old FAO source it is likely that temperatures have changed from the values listed during this period. Anecdotal evidence suggests that this is the case, possibly as a result of increased wetland draining for development in the area. Table 6 shows the difference between Rushamba and Kabale temperature and ET_o values.

Saturation Vapour Pressure Deficit (SVPD)

SVPD at the KGTF site did not exceed the critical value for tea, 2.5 kPa (Tanton, 1982) at 9:00 am. The highest SVPD calculated for the study period at this time was 1.4 kPa. However, as these measurements were based on early morning figures SVPD may still reach the critical value for tea during the day. SVPD and humidity are both functions of temperature.

Humidity

The lowest monthly average daily humidity reading based on mean monthly values from 1997 to 2004 was 75% at Ruhija (altitude 2030 m). However, humidity at both Rushamba and Buhoma was higher according to mean monthly values from 1997 to 2004 varying between 85% and 95%.

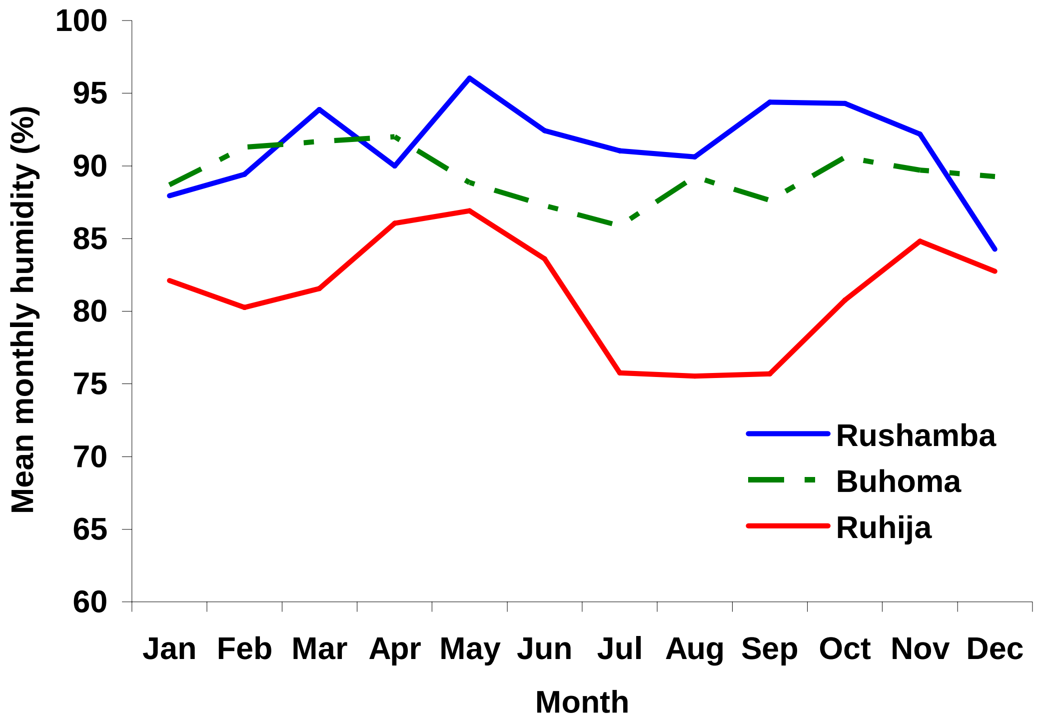


Figure 12. Mean monthly humidity (1997 – 2004) for Rushamba, Buhoma and Ruhija in the KGTF area. Other climatic observations

Hail

Three incidences of localised hailstorms were recorded in the KGTF area at Rwambogo from the period of April to August 2006. These led to leaf damage for some smallholder shambas in the area leading to a halt in plucking, thus reducing the amount of leaf they were able to supply to the factory during the period.

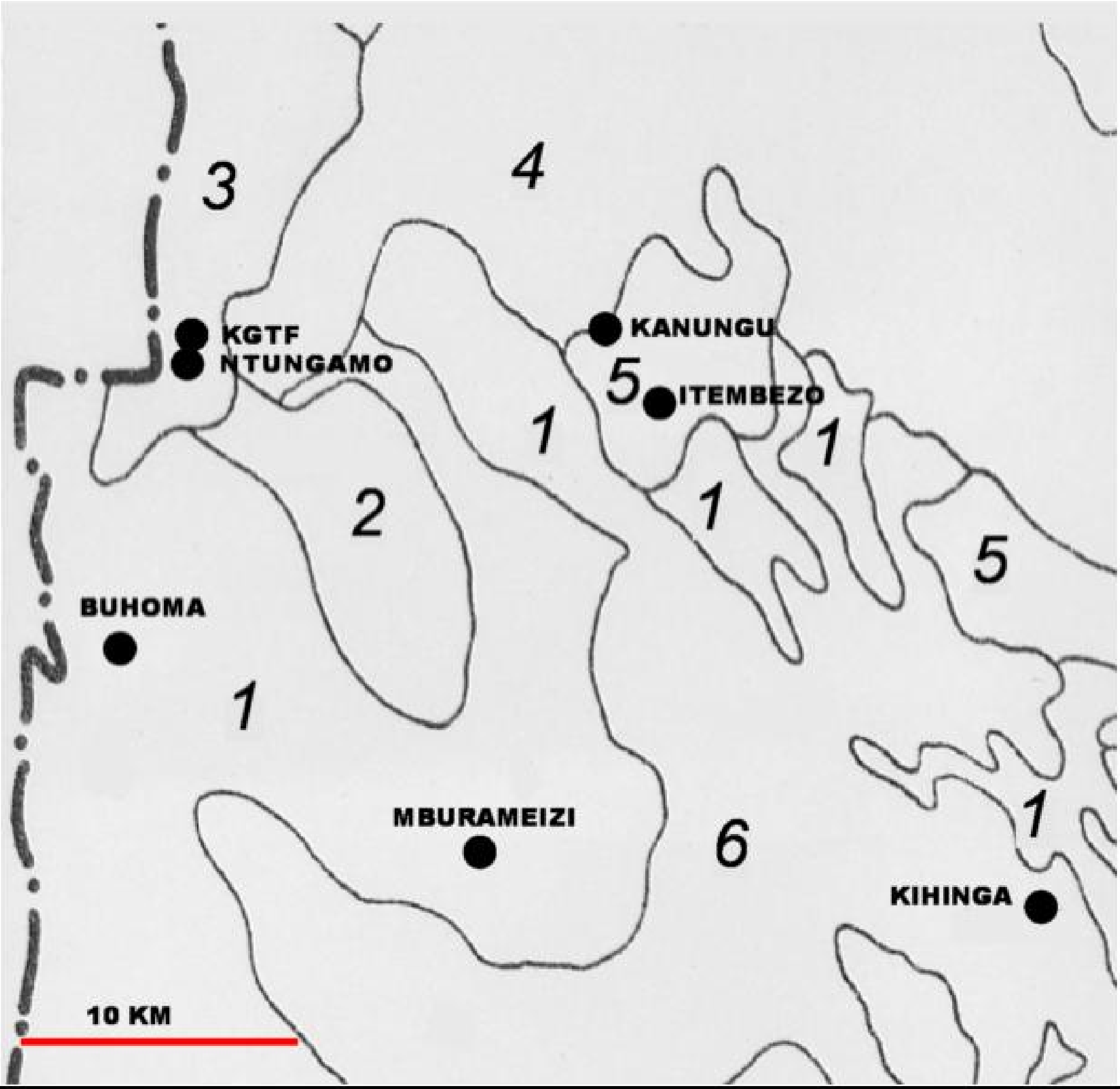
Summary

Mean annual monthly temperatures within the KGTF area varied from 21.1 ˚C at Rushamba (1300 m) to 16.3 ˚C at Ruhija (2080 m). Monthly mean temperatures at a particular site did not vary by more than 3 ˚C. At altitudes above 1700 m and at the highest altitude locations in the area such as Ruhija temperature is likely to be a factor limiting tea yields. However, at lower altitudes such as those at Ntungamo (1080 m) temperature is not likely to limit tea yields.

Mean annual rainfall was also found to vary according to geographical location with the highest location in the KGTF area (Ruhija, 2080 m) receiving the lowest mean annual rainfall total of 1025 mm (1999 – 2005). KGTF mean annual rainfall was found to be 1416 mm for the corresponding period. Double mass curve analysis showed that KGTF and Ruhija had systematically similar conditions both with a slight decrease in rainfall occurring in recent records. Buhoma and Rushamba both had a similar different pattern showing a steady rainfall pattern. KGTF and Ruhija may have experienced changes in measuring conditions or climate. Regression analysis failed to determine a confident correlation between data collected at all sites except for Buhoma which had 18 % more rainfall on average than KGTF. Analysis highlighted potential inaccuracies in data from Ruhija. SVPD and humidity were within acceptable ranges for tea based on calculations for 9:00 am readings. Localised hailstorms have the potential to limit yields where they occur.

4.2 Soil

Parent material of soils in the region is of argillite type with basal quartzite and amphibolites. Soils in the district are classed as clay loams, sandy loams, sandy clay loams and sands and are generally deep and well drained (Kanungu District, 2006a; IPTRID, 1998; Ollier et al., 1968). Soil analyses conducted by Makerere university on 30cm cores of soil from 81 different sampling points in the area concluded that soil type in the area is predominantly sandy loam (Tenywa and Kiirya, 2005). Variations in sand content ranged from 40 to 50 % in Ntungamo and Mafuga to 60 % in Buhoma (Tenywa and Kiirya, 2005). In contrast to this recent soil samples taken over a smaller geographical area but at deeper cores of 70 cm suggest that sandy loam type is predominantly found in the North of the KGTF area with clay loam and loams found in the Southern part of the area (Van Waesberghe, 2005). A soil map of the KGTF area supports this assertion with collection centres such as Ntungamo and Butogota within a 10 km radius of the KGTF in a sandy and sandy loam area while others are in loamy or clay soil areas (Van Waesberghe, 2005, Harrop, 1960. Soil pH in the KGTF area is between 4 and 5.4 which is within an acceptable range for tea (Tenywa and Kiirya, 2005).



Soil area key	
Number	**Soil type**
1	Clay loam/ silt loam
2	Red brown clay loam
3	Deep brown sand occasionally gravely
4	Shallow black sandy loam
5	Red clay loam
6	Dark loam

Figure 13. Soil type map of KGTF area. Adapted from Harrop, 1960.

Potential and actual soil water deficit (SWD)

Potential SWD was initially modelled. Subsequent to this actual SWD was modelled using adjusted parameters. SWD was also modelled according to different rainfall and soil type scenarios. Soil parameters and calculations of TAW and RAW used in the SWD model for the KGTF area are shown in Table 7.

Table 7. Table of parameters used in SWD modelling. Soil values taken from (Hudson, 1975)

Soil type	Clay Loam	Sandy Clay Loam	Sandy Loam
TAW (mm/m)	200	130	100
RAW (mm/m)	80	52	40
P	0.4	0.4	0.4
Root depth (m)	1.05	1.05	1.05
TAW (mm)	210	137	105
RAW (mm)	84	55	42

The potential soil water deficit was calculated for a period of nine years from available rainfall for the KGTF site from 1997 until 2005. A stress day index was also calculated for each soil model in order to ascertain the actual daily stress each day (i.e. total mm exceedance of RAW) and the total number of water stress days. This was calculated using the following 'IF statement' in Microsoft®Excel:

If SWD $\geq$ RAW, $SDIi = SDI_{i-1} + (SWD - RAW)$ …………………(Equation 18)

If SWD < RAW, $SDI_i = SDI_{i-}$ ………………........(Equation 19)

Where SDI_i is water stress on day $_{i.}$

Potential and actual annual SWD

Potential SWD was modelled for a clay loam soil. It suggested that soil water deficit levels were higher than the calculated critical deficit of 84 mm thus potentially impacting upon crop growth. Potential deficit gave an indication of the duration of each period of soil water deficit. Figure 14 shows a period when SWD exceeded the critical deficit for a prolonged period. The potential deficit almost reaches 280 mm which is the most extensive and prolonged period of water deficit. If SWD does reach the modelled actual deficits then approximately half of each year suffers from SWDs that could affect tea production Figure 14.

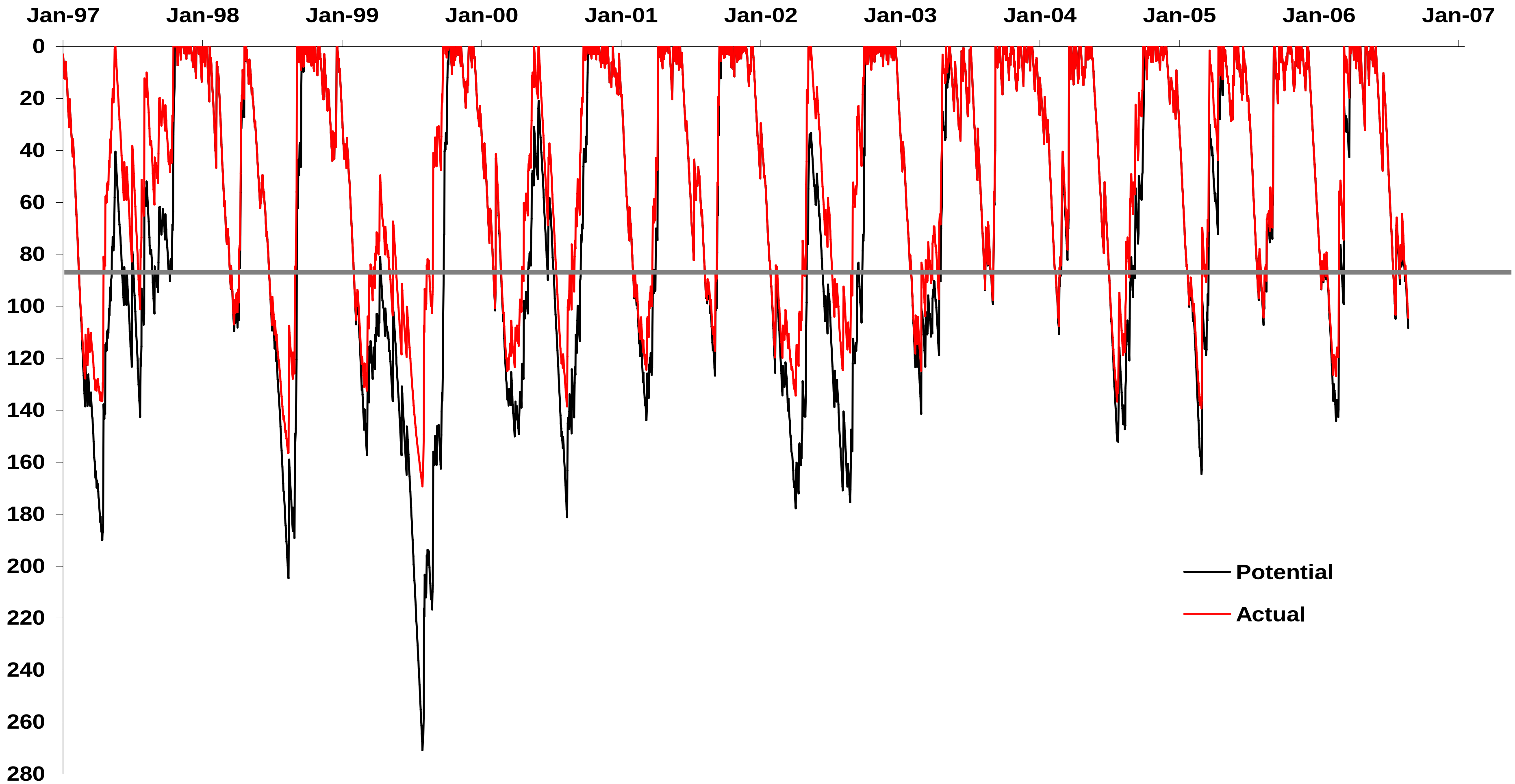


Figure 14 Potential and actual SWD for a clay loam soil under KGTF rainfall conditions.

Soil type and spatial variation

As already identified from soil maps and previous research in the KGTF area, there are two dominant soil types. Sandy loam is the dominant soil type found at collection centres close to the factory (Ntungamo, Butogota and Bikuto). These centres are also considered to be the most drought stressed of the area according to field officer perception (Yield results - Table 9). The collection centre of Ntungamo which is within this area is *"the most drought affected, when the drought comes the whole gardens are affected, maybe just because of the soils"* [14]

A SWD model was created for a sandy loam soil type using the same parameters as the clay loam model with changes made according to soil parameters from Table 7 . Within a sandy loam soil the RAW was calculated to be 42 mm for a 1.05 m rooting plant. Approximately half the water available under a clay loam soil is available to the tea bush within a sandy loam soil. Sandy loam soil was also shown to experience on average 15% or a mean number of 19 days more water stress in a year than clay loam soil (1997 – 2005). However, this figure fluctuated considerably from year to year with a maximum of 40 days and a minimum of 8 days more stress for sandy loam soils

[14] May 24 2006. Wilbroad Omasasisizi. Re: Production in KGTF area.

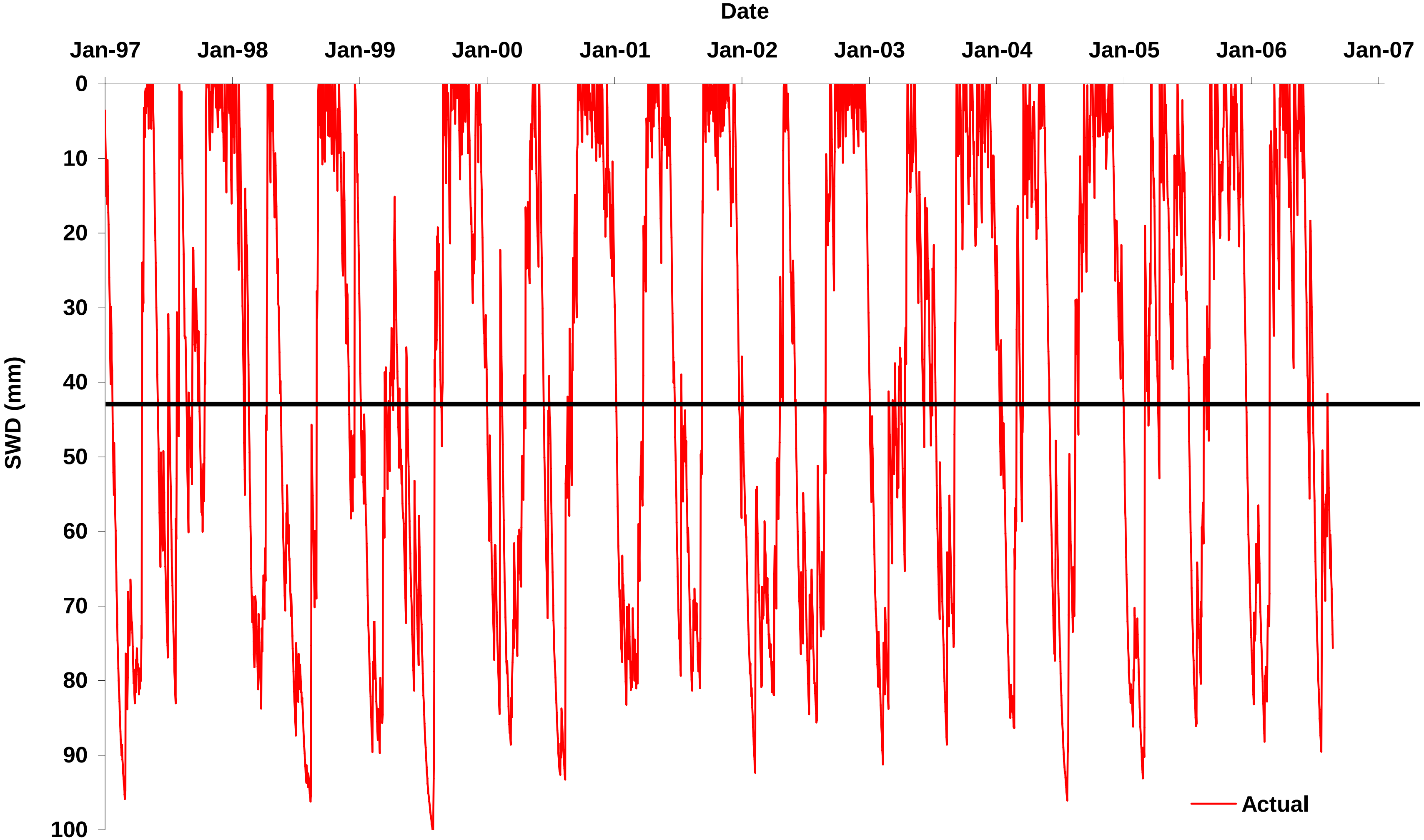


Figure 15 Actual SWD model for sandy loam soil

Water stress day index - seasonal variation

As the rainfall pattern in Uganda is bi-modal the KGTF area experiences two wet and two dry seasons. Mean monthly water stress days are highest from January to April and June to August. There are monthly SWD differences between soils. Mean water stress days in January are 26 and 13 for sandy loam and clay loam soils respectively. The mean number of water stress days in February and March are similar between soils. This pattern is repeated at the onset of the second dry season in June when clay loam soils have half the number of water stress days of sandy loam soils. As sandy loam soils have less RAW than clay loam soils they are more likely to suffer water stress earlier in the season and in contrast they are more readily rewetted to field capacity when the rains start in August.

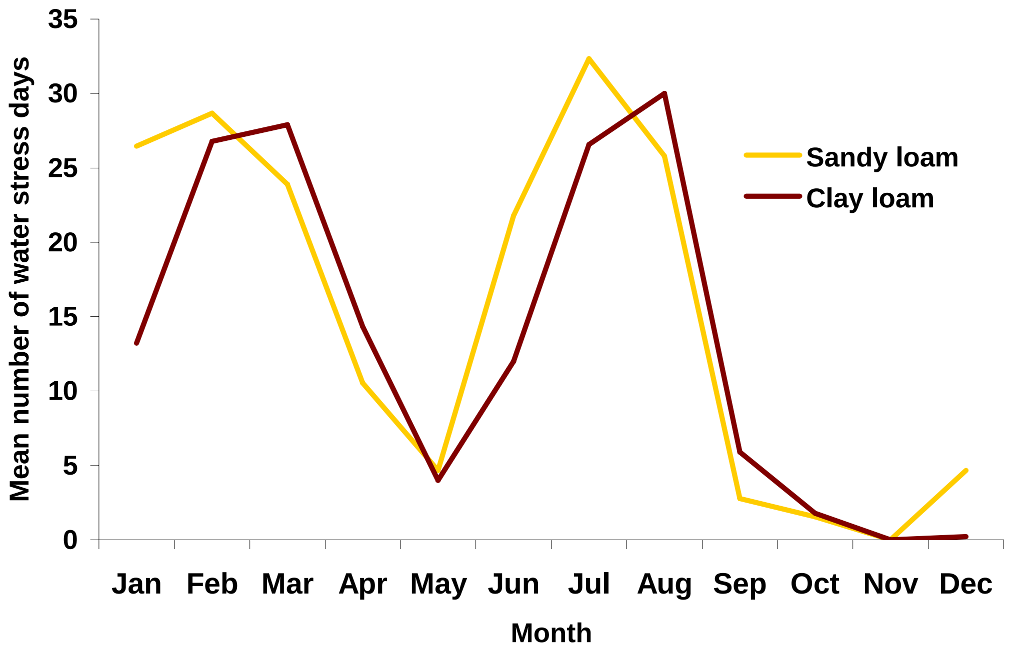


Figure 16. Mean number of water stress days per month for clay loam (critical deficit = 84 mm) and sandy loam soils (critical deficit = 42 mm) (1997 – 2005)

Verification of the model

The SWD model was shown to members of KGTF staff for comment and cross-referenced with information collected from smallholders in the locality. Many of the periods of drought stress identified by smallholders and staff were also supported by the SWD model. For example, as Marcel Asimwe, the production manager at KGTF recounted *"the last drought was in 1999. That one was actually a failure of rain throughout the year and I remember even the factory had to make a provision to provide food for certain communities. I remember we imported a lot of maize from Kampala and distributed it to our smallholders throughout the tea growing area. That was a very bad drought"*[15].

Discussion

SWD modelling was based on several assumptions which affect the results obtained. Soil type parameters for TAW were obtained from Hudson (1975). However, other soil type parameters could have been used. The SWD model is based on climate data from KGTF. Other parameters used such as rooting depth, *p* value and ET_o also affect this model and differences in these would affect the results obtained. Any mistakes in daily calculations are likely to be compounded by the cumulative calculations used in the model. However, these are reset when the soil returns to field capacity.

Summary

SWD modelling shows that there are both annual and seasonal variations in soil water deficits within the KGTF area. RAW was calculated to be 84 mm for clay loam soils and 42 mm for sandy loam soils. Potential SWD modelling for clay loam soil revealed that the extent of drought stress differed from year to year with 1999 the most affected year on record. Actual SWD showed a similar pattern. Both monthly and annual water stress days were calculated. A mean monthly water stress count showed that two dry seasons are experienced in the KGTF area and that these are similar in duration. Soil differences were also observed with sandy loam soils experiencing deficits earlier than clay loam soils. Annual water stress day count showed that 1999 had one of the highest water stress day counts for both soil types (1997 – 2005). This was expected as it SWD models showed it had suffered prolonged periods of water deficit. However, although 2001 was the wettest year in the record it did not have the lowest number of stress days for either soil type. This was probably due to the distribution of rainfall in this year. The

[15] April 18 2006. Marcel Asimwe re:Tea factory production.

lowest water stress day counts were in 2004 and 2005 both years with rainfall close to the mean rainfall distribution pattern.

4.3 Yield

Fluctuations in leaf received

Made tea from green leaf

The proportion of made tea (MT) to green leaf (GL) has remained between 21% and 22% according to factory GL and MT records (1996 to 2005). Anecdotal evidence from production staff suggests that quality is affected by GL received. Areas at high altitudes such as those at Mburameizi (centre number 16) and Kihinga (centre number 33) tend to supply a better quality of leaf although in smaller quantities than those at lower altitudes. This is reflected in the lower mean kg ha^{-1} (1996 – 2005) recorded at these sites.

Annual fluctuation

MT figures from the last ten years indicate that yield has increased from an average of 850 kg in 1996 to 1400 kg in 2003.

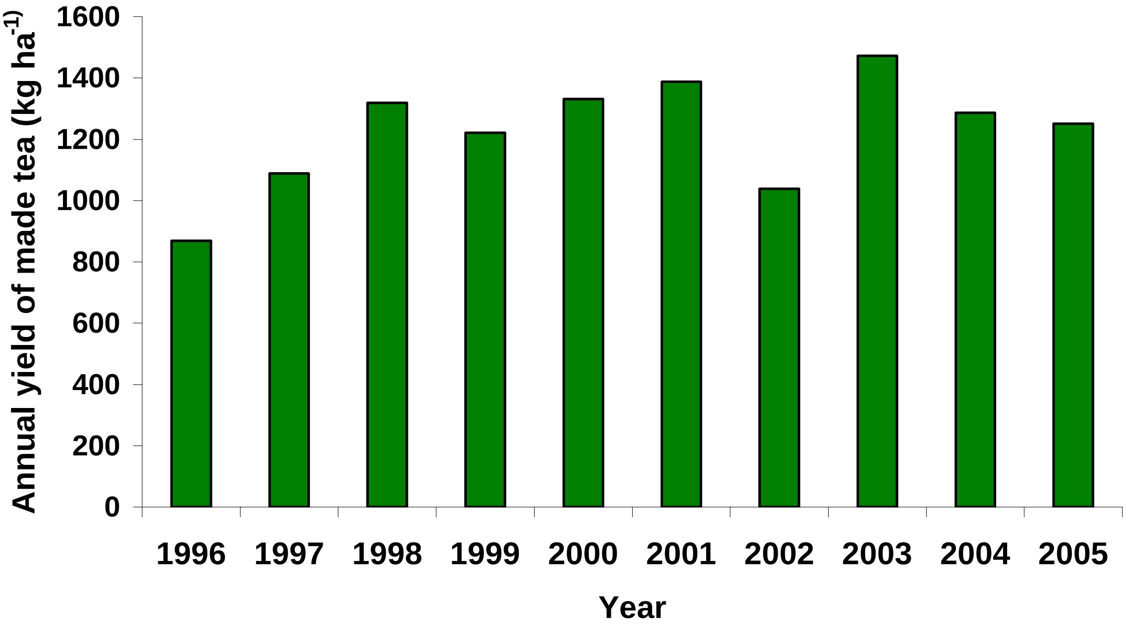


Figure 17 Kg ha^{-1} made tea 1996 – 2005. Based on ha change as recorded on the KGTF database including KGTF estate yield.

Yields appear to have increased steadily although there were unusually low yields in 2002 (Figure 17). Although 2002 was considered to be a year that suffered from a *"minor drought"*[16] it was not considered to have had as large an impact on yield as 1999. It is possible that hectarage on the KGTF database may not be accurate. Despite evidence to suggest 1999 suffered from the most extensive and prolonged SWD in the record, it doesn't appear to have suffered as great a drop in yield as 2002.

Seasonal fluctuations

Changes in Kg of MT produced by the factory are not limited to annual figures. KGTF also experiences seasonal fluctuations in green leaf received from smallholders as evidenced from mean monthly totals of green leaf received as calculated from green leaf receipt[17] data (Figure 18). Peaks in green leaf supply from April to June and October to December can be observed. This is based on green leaf received between 1996 and 2005.

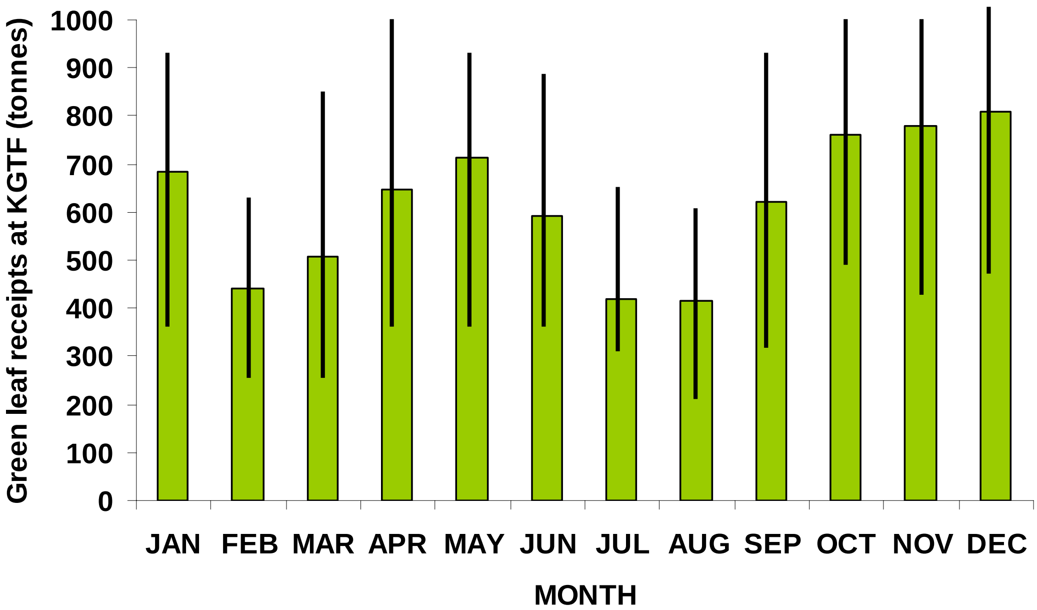


Figure 18. Seasonal fluctuation in mean green leaf received at the factory according to delivery receipt data (tonnes) from 1996 to 2005. Lines show the approximate minimum and maximum green leaf obtained in any given month from 1996 to 2005.

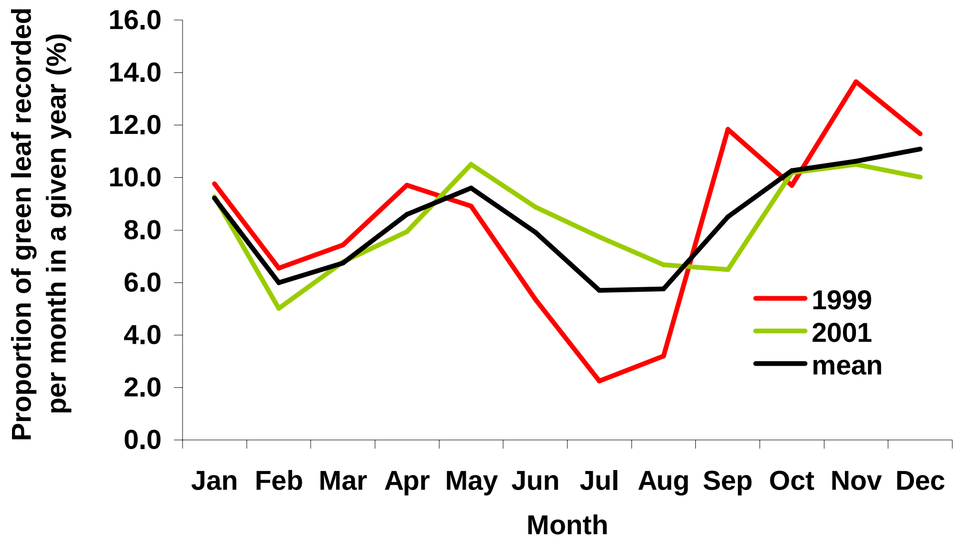
[16] April 18 2006. Marcel Asimwe. Re: Factory production.

[17] Green leaf receipts are the receipts given to farmers when they hand over their plucked tea leaves at the collection centre. Receipts record the amount of leaf handed over in Kg and are proof of the farmer's green leaf contribution. Farmers receipts are converted to payment at the end of the month. The factory keeps a record of green leaf receipts in order to calculate farmer payments.

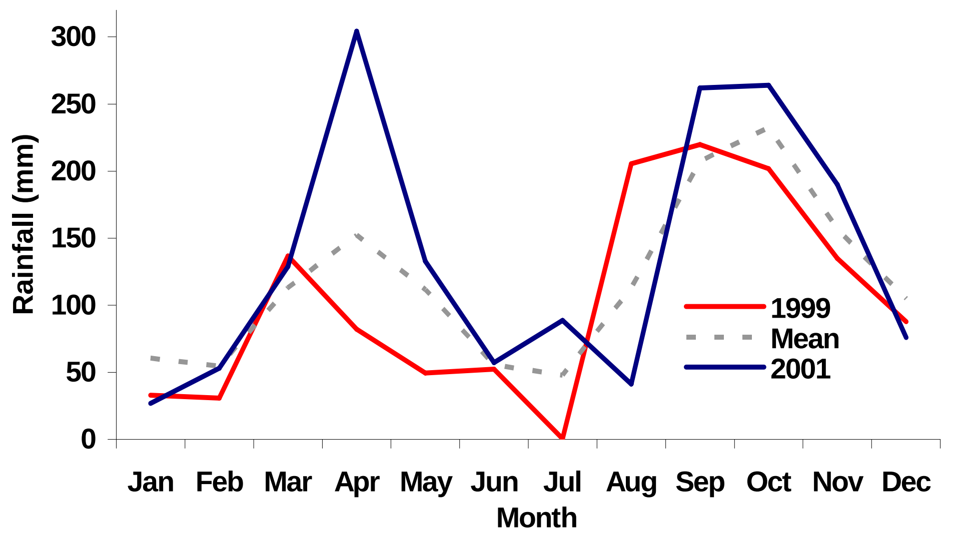
The lowest mean proportion of crop received in a month is 6% of the mean annual production (1996 – 2005). This is the mean proportion received in February, July and August. The largest peaks are in November and December which receive a mean of 11 % in a year.

Variations in annual yield distributions 1999, 2002 and 2005

A comparison of crop received in the driest year with crop received in the wettest year demonstrates this annual and seasonal variability. Comparison of July 2001 (annual rainfall 1624 mm) shows that the percentage of annual crop received in this month was 5 times greater than that received in July 1999 (annual rainfall 1233 mm) (Figure 19).



a). Variation between 1999, 2001 and mean monthly percentage of crop received as a proportion of annual crop production



b) Monthly rainfall (mm) at KGTF for 1999, 2001 and mean year.

Figure 19 a & b. Proportion of annual green leaf received and rainfall (mm) in each month for 1999, 2001 and mean year.

1999 was the most uneven year in terms of monthly yield distribution (1996 – 2005) with a standard deviation value of 3.5 %. By comparison, 2001 had a more even yield distribution with a standard deviation value of 1.8 %. This may be a result of difference in seasonal rainfall distribution. 1999 had one of the most uneven yields and most uneven rainfall distributions (St.Dev 6.1) Figure 20.

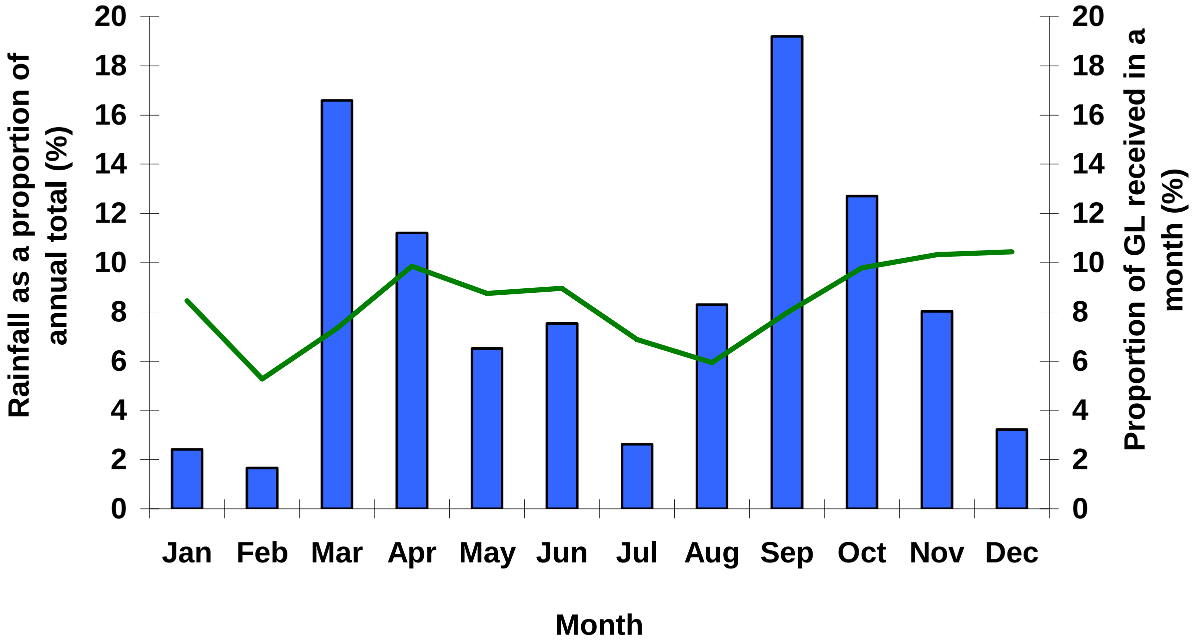


Figure 20 Rainfall as a proportion of annual total (%) and yield as a proportion of annual total (%) for 2005

Yield Prediction

Yield prediction calculations estimated a potential made tea yield of 2300 kg ha^{-1} even accounting for drought stress (Table 8). The average smallholder yield in 2005 was 1250 kg ha^{-1}. This compares favourably with yields from other smallholder tea producing regions in East Africa such as Tanzania where smallholder made tea yields can average 400 to 500 kg ha^{-1} (Carr et al., 1992). This suggests that distribution could be one of the biggest problems at KGTF. This is supported by management experiences: "*during the month of Feb the factory here received about 350 000 [350 t] kg of green leaf. Against a budget which anticipated a drought but less severe of 550 000 kg [550 t]"*[18]. This demonstrates the difficulties in planning for potential leaf production.

[18] April 24 2006. Marcel Asimwe. Re: Factory production.

Table 8. Potential annual yields under non drought stressed and drought stressed conditions.

Total Intercepted Solar Radiation $MJ/m^{-2}/d^{-1}$	Radiation Use Efficiency g/MJ^{-1})	Total Dry matter production $g\ m^{-2}$	Harvest Index	Made Tea Yield $g\ m^{-2}$	Made Tea Yield Without Drought $kg\ ha^{-1}$	Made Tea Yield Without Drought $t\ ha^{-1}$	Actual Made Tea yield with drought $kg\ ha^{-1}$
5777	0.4	2310.7	0.1	254.2	2541.8	2.5	2330.1
			0.2	369.7	3697.2	3.7	3389.2
5777	0.5	2888.4	0.1	317.7	3177.3	3.2	2912.6
			0.2	462.1	4621.5	4.6	4236.5
5777	0.6	3466.1	0.1	381.3	3812.7	3.8	3495.1
			0.2	554.6	5545.8	5.5	5083.8
5777	0.8	4621.5	0.1	508.4	5083.6	5.1	4660.1
			0.2	739.4	7394.3	7.4	6778.3

As the yield predictions demonstrate, the difference between actual and potential yield calculations under drought stressed conditions is small at around 10%. This calls into question the economic viability of irrigation

Green leaf yield produced per hectare

Yields of green leaf (GL) per unit area vary considerably according to collection centre (Table 9). In 2005 mean GL per hectare was 5592 kg ha^{-1} in the KGTF area. However, there is variation between collection centres. The lowest mean annual yields (1996 – 2005) were found at Bikomero (106 kg ha^{-1}), Mburameizi (697 kg ha^{-1}) and Kazuru (695 kg ha^{-1}). This is in comparison to 5975 kg ha^{-1}at Rwambogo. The low annual mean at Bikomero could be explained by the small number of farmers at the centre, its' very recent production record starting in 2004 and the recent establishment of young tea in the area. Mburameizi collection centre covers Mburameizi and Ruhija and is located at one of the highest altitudes in the KGTF area (alt.:1970 m to 2080 m) which may constrain yield there. Rwambogo collection centre (alt.:1300 m) is in an area not considered to suffer from drought stress, it also has an even yield distribution. The high yield supports these observations. Although, the collection centre suffers from hailstorms occasionally this does not appear to have affected total yields per unit area.

Ntungamo collection centre covers the shed at the KGTF and has a mean annual yield of 2637 kg ha^{-1}. However, estate yields alone are 6493 kg ha^{-1} according to database records (1995 – 2006). This is a high figure even accounting for the changes in hectarage which have taken place. Yields may be greater on estate land as the estate is likely to have more consistent management than a smallholder plot. Ntungamo is at the lowest altitude in the KGTF area (alt.:1080 m) and so unlikely to be constrained by altitude. The record for this collection centre area is likely to be the most complete of the whole KGTF area due to the proximity of sheds to the factory and so field officers and management can see changes in production first hand. Butogota collection centre which is located at the same altitude has a mean yield of 3566 kg ha^{-1}. As soil type and drought stress ranking are the same for this area as Ntungamo other factors may be influencing mean annual yield figures at these two locations.

Yield distribution

Consistency of monthly GL yield distribution was used as a starting point for investigating the extent of yield fluctuation in the KGTF area. Evenness of yield was determined by standard deviation figures per collection centre which showed that most collection centres had a standard deviation of 2 ranging from 2.01 to 2.70 (Table 9). Three collection centres had standard deviation figures above 2.50. Kihembe, Bikomero and Ntungamo. Kihembe and Bikomero both have small numbers of farmers, 18 and 11 respectively which could have affected the standard deviation figure obtained if managerial decisions or a sudden weather event had affected the centre. A comparison of the proportion of GL received from three collection centres, Bikomero with the highest standard deviation (5.76), Ntungamo (2.67) and Rwambogo with one of the lowest (1.34) shows the difference in proportion of yield received during the year (Figure 21).The highest variation in evenness of yield (standard deviation 5.76) could be due to the small number of farmers at the centre, it's very recent production record starting in 2004 and the recent establishment of young tea in the area.

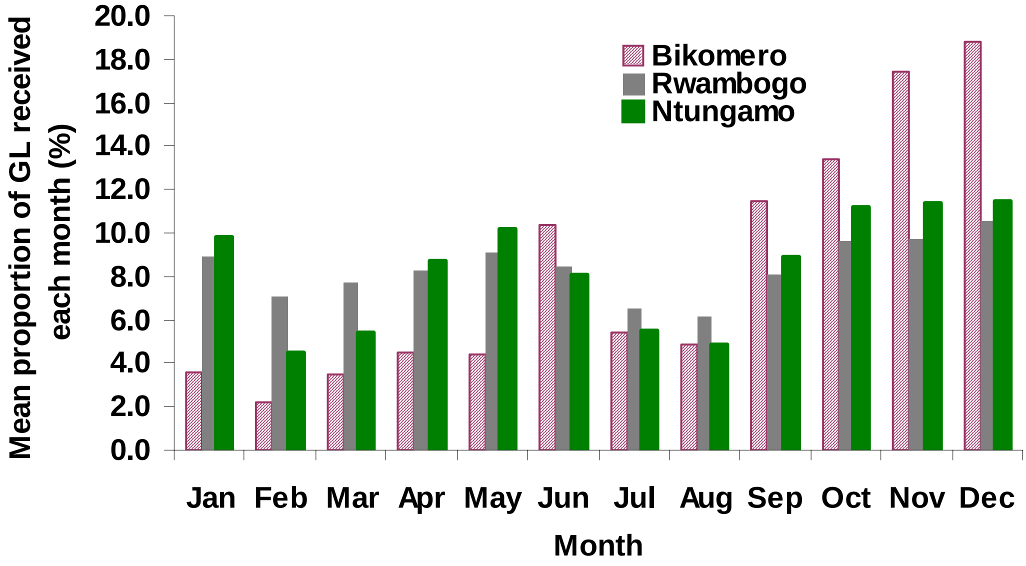


Figure 21 Comparison of Bikomero, Rwambogo and Ntungamo mean collection centre yield as a proportion of the total received 1996 – 2005.

The eleven centres with the highest standard deviation values (5.76 – 2.01) are predominantly located within the vicinity of the KGTF. Most are also considered to be suffering from severe drought stress by field officer staff from KGTF (Table 9). Standard deviation values also broadly correspond with field officer perceptions of drought stress. Kihinga and Bikomero are exceptions. Their uneven yields could be due to the aforementioned reasons for Bikomero and in the case of Kihinga may be due to difficulties at some collection sheds in accessing inputs or transporting leaf to the shed for collection. These social factors could affect the proportion of annual green leaf received in a year. The seven collection centres with the highest evenness of yield could not be linked to a geographical area.

Table 9 Collection centre total GL yield and standard deviation

Collection centre number	Centre name	No.of farmers	Total ha of area	Average ha per farmer	Total Kg GL received (1996 - 2005)	Mean Kg ha^{-1} per farmer (1996 – 2005)	Field officer drought stress ranking 1. Severe 2. Medium 3. Little 4. None	Standard deviation (2 decimal places)
1	Kanyashogi	361	93	0.3	3968344	4256	3	1.43
2	Kanyamisinga	323	141.8	0.4	4123212	2907	3	1.26
3	Rwambogo	191	55.3	0.3	3304075	5975	3	1.34
4	Mayanja	367	148.3	0.4	5958010	4018	3	1.92
5	Karangara	342	129.5	0.4	6146010	4747	3	2.07
6	Kishanda	609	258.3	0.4	9412000	3644	3	1.67
7	Kagunga	152	106.4	0.7	4980970	4680	3	2.34
8	Bikuto	70	34.2	0.5	1980656	5790	2	2.30
9	Kerere	163	95.9	0.6	3856751	4022	3	1.77
10	Butogota	161	94.2	0.6	3359957	3566	3	2.01
11	Ntungamo	216	118.3	0.7	3120484	2637	3 – 4	2.67
12	Kyabuyorwa	37	24.0	0.6	918565	3824	3	2.44
13	Ishasha	92	43.5	0.5	1484835	3410	3	2.15
14	Nyamigoye	211	97.5	0.5	2761504	2833	3	2.02
15	Rubimbwa	171	74.8	0.4	1695267	2265	3	1.67
16	Mburameizi	74	6.2	0.3	42848	697	3	1.72
17	Bushenshero	67	32.4	0.5	995133	3070	3	1.59
18	Rutugunda	57	25.0	0.4	920688	3684	3	1.50
19	Kanyantorogo	8	2.4	0.3	28800	1195	4	1.52
20	Kitariro	44	11.9	0.3	334554	2814	3	1.58
21	Bushura	41	15.8	0.4	394728	2501	3	1.84
22	Kazuru	46	46.9	1.0	326427	695	4	1.77
23	Nyakatale	51	22.9	0.4	548281	2395	4	1.00
24	Masya	61	11.1	0.2	417061	3767	3	1.26
25	Kijubwe	44	15.2	0.4	243844	1608	1	1.63
26	Itembezo	151	74.3	0.5	1210618	1629	1	1.76
27	Nyarurambi	114	27.2	0.3	723269	2657	1	1.90
28	Kashojwa	19	3.9	0.4	88098	2265	1	1.53
29	Omumbuga	92	22.0	0.2	784139	3566	3	1.66
30	Kabale	15	3.4	0.2	110021	3255	1 – 2	1.46
31	Mashuri	64	25.9	0.4	992904	3840	2 – 4	1.84
32	Katagyirameiz	89	18.2	0.2	676391	3725	1 – 2	1.82
33	Kihinga	124	50.6	0.4	1078374	2132	1	2.21
35	Kihembe	18	9.6	0.5	222054	2320	1 – 2	2.70
36	Bikomero	11	3.5	0.3	3687	106	2 – 3	5.76

Variation in smallholder yield evenness within a collection centre

Individual smallholder standard deviations for yield showed a wide variation not only between but within collection centres. Figure 22 gives an example of the variation in mean individual smallholder annual green leaf production at collection centre 3, Rwambogo (1997 – 2005). Production at this centre is one of the most even in the KGTF area and it is not in an area considered to suffer from drought stress. However, it is clear that there are other factors besides drought stress affecting yield obtained at this collection centre locality.

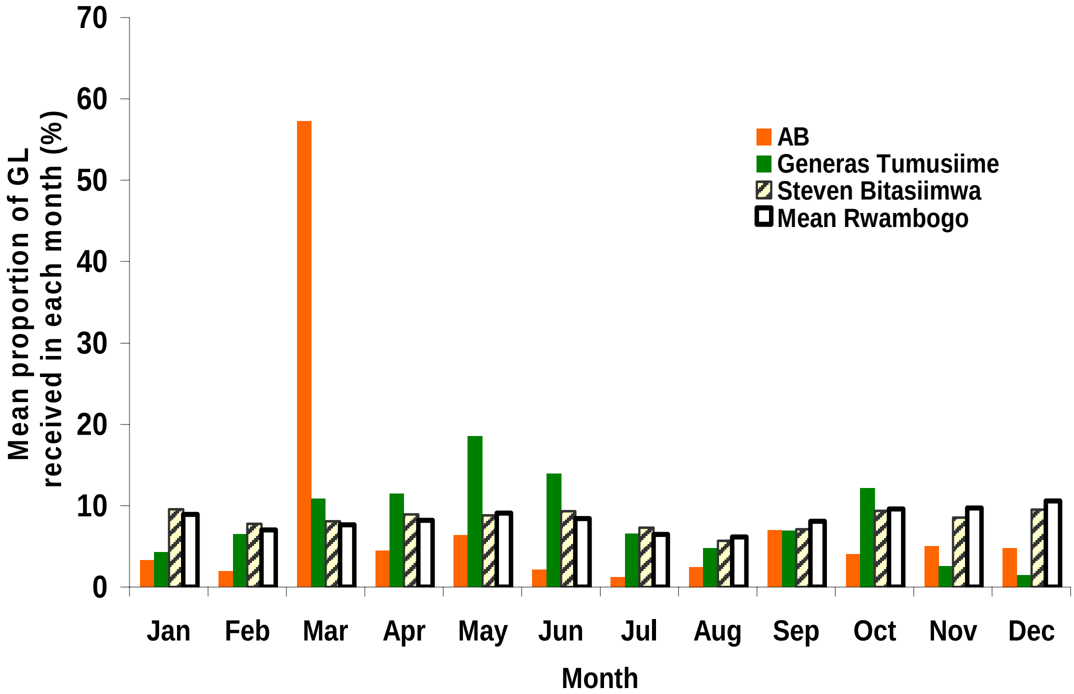


Figure 22 Average monthly production for three smallholders at Rwambogo collection centre (3) 1996 - 2005

Soil water deficit and tea yield variation

If potential SWD for two contrasting collection centre localities is modelled using available information a relationship between SWD levels and yields can be observed. Ntungamo has a KGTF rainfall pattern, sandy loam soil and an uneven yield pattern. Mean annual (1996 – 2005). GL yields are lower than the average for the KGTF area . Rwambogo is a clay loam soil area. It is close to Bwindi and is considered to receive greater rainfall than Ntungamo. Therefore, it has been modelled with 18% more rain than Ntungamo . Yield distribution is one of the most even in the KGTF area and mean annual GL yield is above the KGTF area mean.

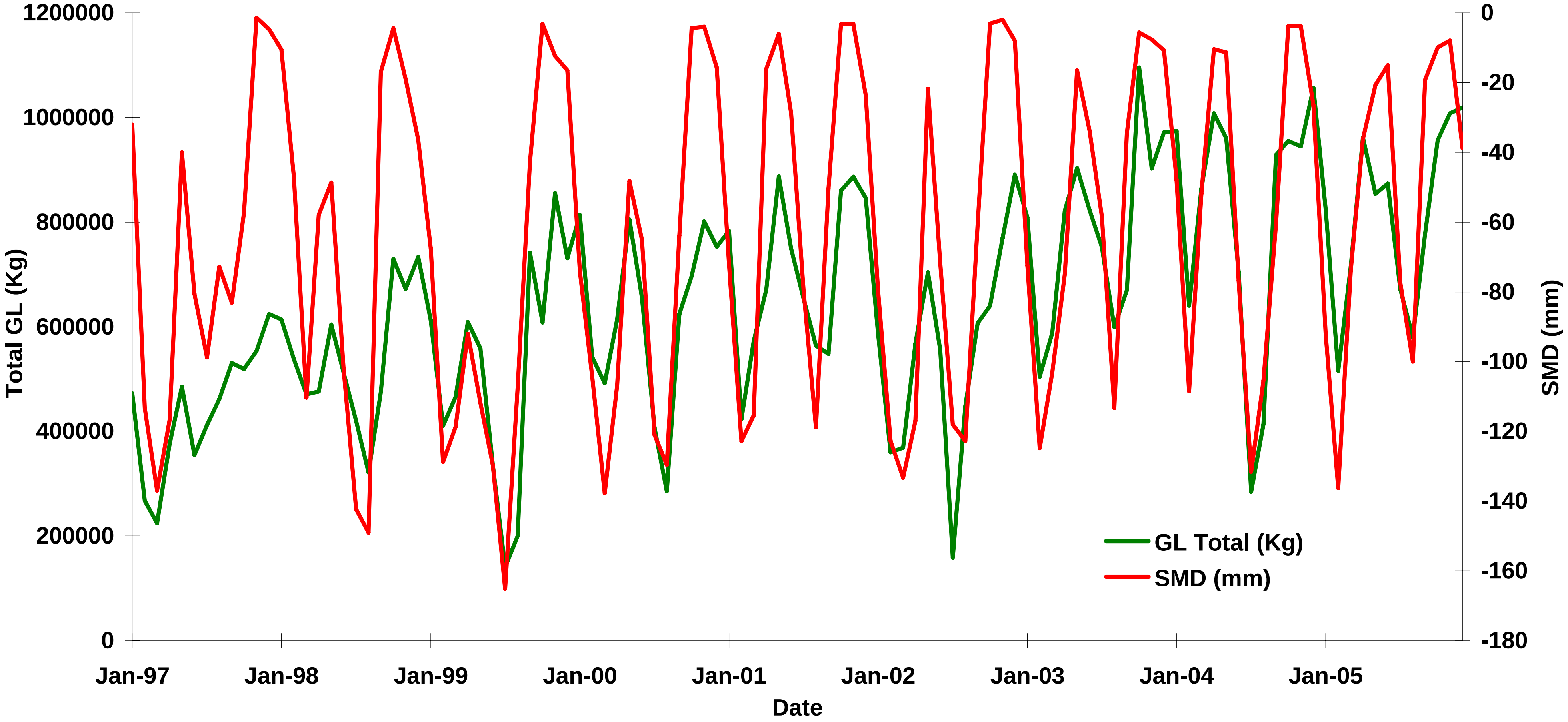


Figure 23 Ntungamo monthly average daily SWD (mm) and total GL (Kg) 1997 – 2005.

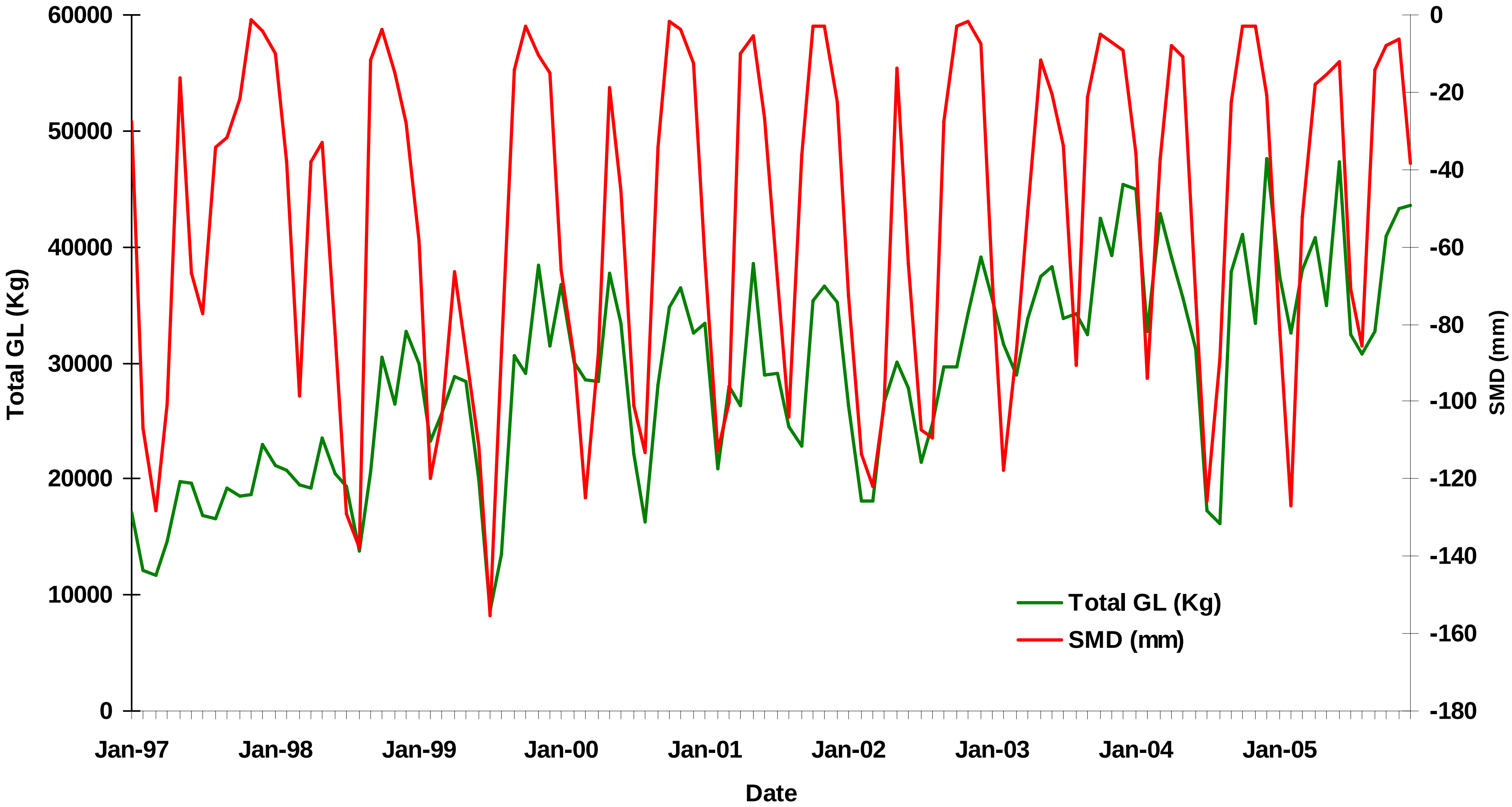


Figure 24. Rwambogo monthly average daily SWD (mm) and GL yield (Kg).

Discussion

All calculations assume that the hectarage values recorded on the KGTF database are accurate. This is unlikely as hectarage values are not updated on a regular basis. During research it was also discovered that smallholder hectarage was often different from that recorded on the database. Nevertheless, the variability in yield does give an idea of the difficulties the factory faces in terms of maintaining constant yields per hectare. The area of tea production recorded for some smallholders in relation to their yield data was found to be inaccurate for the following reasons:

- - A tea shamba may have been sold or an additional one bought by the smallholder.
- - A portion of the tea shamba may have been abandoned.
- - A smallholder may rent out or hire a shamba for a period of time ranging from months to years in a sharecropping arrangement.
- - Land inheritance in the KGTF area means that plots may be split up between several members of the same family.
- - A spouse may hold an additional smallholder number under which green leaf for one or more shambas is recorded.
- - A shamba under a different farmer number may have been inherited by the smallholder.

Yield figures may also fluctuate due to informal green leaf markets (Box 6)

Box 6. Informal green leaf sales

Individual smallholder green leaf production figures may be subject to fluctuations not associated with climatic or physical environment factors. One possible reason for this may be due to smallholder sale of green leaf (often at a lower price than the factory gives) to another smallholder in order to obtain cash instantly or in order to avoid payment being deducted by the factory for fertilizer and pesticide purchases. As Precious*, a single mother supporting six children stated *"Payment for tea is at the end of the month so sometimes can't wait that long. If I'm short of money I sometimes sell tea to another farmer for less money so I can get cash immediately and I'm not waiting especially if the children have expenses"*. A change in factory policy to now allow advance payment of a proportion of tea income each month based on predicted kg may help to alleviate this situation. However, some smallholders suggested the situation was highly organised *"they don't even have a real shamba but make their money from selling leaf, they* [the factory] *know it happens".*

* name has been changed.

Summary

Annual yields have generally increased steadily from 800 to 1000 kg ha^{-1} of made tea (1996 – 2005). Average yield of made tea per smallholder was 1250 kg ha^{-1} in 2005. However, potential yield calculations estimated a possible made tea yield of 2300 kg ha^{-1}. Yield variations can be summarised as follows:

Seasonal variation. There is seasonal variation in green leaf received by the factory. May, November and December were shown to the highest proportion of annual crop production of 10 to 11 % while February, June and July received the lowest at 6 %.

Variation in evenness between years. Yield evenness was shown to vary between years with 1999 possessing the least even yield distribution and 2005 the most even. However, total yields received each year did not vary considerably.

Variation in yield evenness between collection centres. Field officer drought stress ranking for collection centres was supported by yield evenness ranking as determined from standard deviation values. Yield evenness was found to vary between collection centres which may in part be due to different soil conditions and rainfall. Differences in soil, rainfall and yield response could be roughly split into two geographic areas. Seven centres with the least even yields are located in the vicinity of the KGTF at altitudes between 900 and 1200 m in an area characterised as sandy loam. Those with the most even ranking were not attributable to a specific geographical area. Monthly SWD were plotted alongside monthly yields from 1997 to 2005 for a Ntungamo and a Rwambogo scenario. Yield evenness was shown to vary between individual smallholders at the same collection centre site. This may be due to factors other than climatic or soil characteristic differences between sites.

4.4 Sociological context – Results and analysis

Demography

There are 4072 smallholders currently supplying green leaf for KGTF production. 58% of smallholders have tea shambas consisting of 0.25 ha or less while 83% of smallholders have tea shambas of less than 0.45 ha (Figure 25). Shambas of less than 0.25 represent a very small parcel of land. Production from a shamba of this size is likely to be low and may affect the extent to which a farmer will be able to access inputs or their time investment.

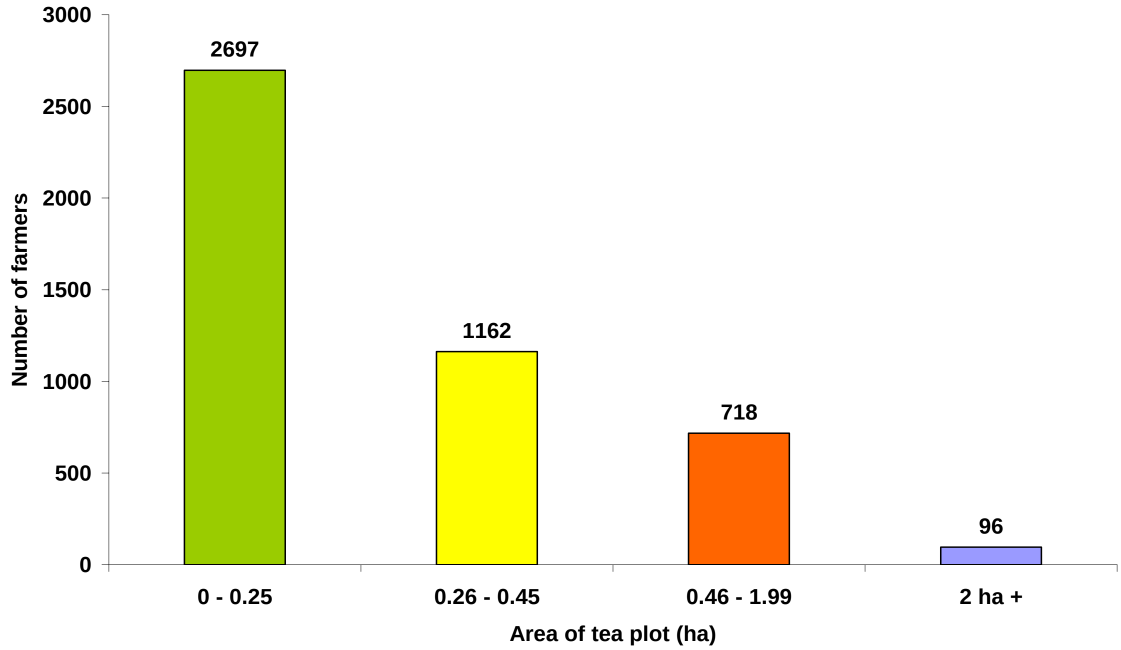


Figure 25. Hectarage of smallholder tea producers supplying KGTF.

Farming system

The composition of the farming system in the KGTF area can be viewed as a collection of different components which comprise the whole farm system. Farming system composition may vary according to geographic factors such as altitude, regional climatic differences or the proximity to Bwindi forest as well as socio-economic factors such as access to land and economic markets. For example, smallholders may avoid cultivation of fruit trees and beans in areas bordering the forest to avoid losing the crop to baboons and other primates. Crop choice may also vary according to geography with

Matooke less cultivated at lower altitudes in the northern part of the district (although just out of the KGTF area) as the soils are drier and the sub-climate is thought to be less moist. The various components comprising the farming system can be categorised as follows:

Tea

Tea production represents a major component in the local farming system. Unlike other internationally traded cash crops like rice and coffee, it generates a regular, consistently priced monthly income. However, tea production is often labour intensive, requiring regular work and weekly plucking during the wet seasons to obtain a maximum yield. For smallholders and their families this may constitute a disproportionately large proportion of farming activity.

Livestock

Livestock represent an important aspect of financial capital in the local farming system frequently constituting a form of savings and investment. Few individuals own large numbers of livestock. Wealthy smallholders may accumulate large numbers of cattle. Goats, sheep, pigs, chickens or rabbits serve a similar investment or savings function.

Cash-crop

Although most crops can be sold if surplus is produced cash crops have been defined here as those which tend to be grown predominantly for cash production or recently introduced for that purpose. Coffee, rice, grapes, chilli, okra, matooke, tobacco and tomatoes. I have included matooke in this category as most smallholders view it as an important cash crop. Rice is also included here as its introduction was the result of a government intervention to create a sufficient supply for internal markets and potentially regional export.

Subsistence

Generally crops that constitute this sub-system are grown solely to provide food for the family first. Crops such as dodo, jhia nuts, peas, beans, millet, sorghum, cassava, yam, avocado, mango, and jackfruit. Subsistence crops may also be grown on a large scale by entrepreneurial smallholders who have recognised a market niche to exploit and have the land available to do so. This is the case with potatoes, peas passionfruit and mango. Although, there is no intervention encouraging production for a specific market a project is due to start in 2006 the Bwindi area encouraging smallholders to produce vegetables and livestock for tourist camps who currently transport goods from Kampala.

Timber

Eucalyptus and pine are two commonly grown timber trees in the area. These can constitute a form of savings in that initial investment increases once the tree is mature. Eucalyptus may be used for fuel wood by the household or sold to the tea factory or surrounding families for fuel use. Pine is commonly grown in Mafuga and is usually bought by the local forestry department for processing in Kampala.

Additional industries

Additional farm based industries include mat and basket making for local sale and brick making. Mats are made using rushes and reeds commonly found in wetland areas which are then woven using string or nylon into the desired shape. A medium sized basket can take one to two weeks to produce and be sold for between 5000 and 15 000UGX [19]. Profits from the sale of these are between 2000 and 5000UGX [20]. Proximity of some communities such as Buhoma to the Bwindi forest entrance means that smallholders obtain some benefit from the tourist market locally, *"when visitors come we can get a*

[19] July 22 2006. Jovia Karambuzi & June 29 2006. Stephen Bitasimwe. Re: Costs of baskets.
[20] June 29 2006. Stephen Bitasimwe. July 25 2006. DE Kakawata. Re: Profits from mat making & basket work.

market for the matooke and can weave baskets to sell for money"[21]. Brick making is another local industry that is always in demand. This has been particularly successful in areas such as Buhoma which have seen swift construction in the past few years due to the creation of campsites and hotels for tourists.

Figure 26. Timber post logging in Rutenga.

Figure 27. Brick making Kiln in Mburameizi.

[21] July 22 2006. Jovia Karambuzi. Re: Additional sources of income & impact of tourism.

Land preparation

Land is prepared for cultivation by cutting down old vegetation and weeds then burning the debris before hoeing and turning the soil. This may take a period of 2 to 3 weeks. The reasons given for burning the soil included faster germination times for seeds and better establishment of the crop. This was seen to be especially true for sorghum.

Figure 28. Burning weed bundles to prepare the soil for planting.

Figure 29. Women's group in Mafuga hoeing land to prepare it for planting.

Intercropping

Matooke is frequently grown with other crops. Pumpkins, chillies, tomatoes, dodo and coffee are all commonly found in matooke plantations. Beans and maize are also commonly intercropped. In high altitude areas close to the pine forests in Mafuga crops may be grown alongside young pine. Less commonly potatoes or beans may be grown in the same plot as young tea.

Figure 30. Young pine trees, yams and potatoes next to a sorghum plot.

Agricultural regime

A summary of agricultural activities undertaken during the year is given in Table 10.

Table 10 Planting dates from fieldwork data

Crop	Land Preparation	Crop Growth	Harvest
Maize	Feb – Mar Aug – Sep	Mar – Aug Sep – Dec	Jun – Aug Dec – Jan
Beans	Jan – Feb Jun - Jul	Mar – Jun Jul – Oct	May - Jul Oct – Nov
Vegetables	Feb – Mar Aug-Sep	Mar – Jun Aug – Nov	Apr – July Nov – Dec
Rice	Jan – Mar	Mar – Jul	July
Bananas	Feb – Apr		Continuous
Potatoes	Jan – Apr Sep - Nov	Feb – Aug Oct – Feb	Apr – Sep Apr – May
Passion fruit	Feb – Mar	Mar – Dec	Continuous

The planting dates can be seen as reflective of rainfall patterns with planting generally occurring at the start of the rains, possibly so that crop establishment occurs when there is maximum water available. Crops such as potatoes may follow other planting dates than those specified in areas where there are valley bottoms allowing for irrigation. Management activities for tea are outlined in Box 7.

Box 7. Tea management regime

"When there are weeds I weed. When there are leaves I pluck them" Generas Tumusime. The extent to which smallholders employ management techniques varies. Tea can be a labour intensive crop requiring monthly and often weekly attention in order to obtain maximum benefits. Typical annual management activities are shown in Table 11 Tpical monthly management. This is in addition to weekly plucking during wet seasons (which depending on the size of shamba may take several days to complete). Crop flushing periods are likely to be periods when labour demand increases in order to harvest all the leaf produced by the plant.

Month	Activity
January	Tipping
February	Tipping
March	Fertilizer. NPK
April	Crop flushing
May	Crop flushing
June	Crop flushing
July	Dry. Tipping & skiffing
August	Dry. Tipping & skiffing
September	Fertilizer. NPK
October	Crop flushing
November	Crop flushing
December	Crop flushing

Table 11 Tpical monthly management activities undertaken by John and Nora in Kishanda

Small scale irrigation and dry season coping strategies

Due to the bi-modal rainfall pattern smallholders have two distinct rainy seasons which enable two harvests of many annual crops such as beans, maize, rice and millet in a year. Smallholders may time planting of annual crops to coincide with rain for initial germination as is the case for millet. Deviations from expected rainfall patterns in any season can affect harvesting times and household food availability. This may occur due to rains arriving earlier than expected as occurred in August 2006 when sorghum crops had to be harvested rapidly in order to prevent re-germination or mould. Perhaps unsurprisingly smallholders highlight the dry season as the worst for agricultural production *"June and July are the worst because firstly everything is harvested and secondly there is always a drought."*[22]. The nature of the farming system means that the start of the dry season is also the start of harvesting. It is a period for weeding and land preparation in order to resume planting before the rainy season begins in earnest.

This is also a period associated with scarcity *"when crops do not grow well and the harvest is little"*[23]**.** However, smallholders have developed strategies to deal with dry seasons. These include, timing of crop planting to ensure a crop is mature and ready for harvest when the dry season is at its worst and planting just before the onset of the rains, putting water onto crops or cultivating in the dry season around waterlogged areas such as next to streams and wetland swamps. *"There is no business of watering and irrigation – they resort to this wetland. That is where there is planting food crops like cabbages, yams, maize, beans"*[24]

Other smallholders may choose to apply water to a crop using a can or spray pump, *"When it is dry we sometimes put water onto our cabbages using a jerry can"*. [25] Knowledge of when to irrigate comes from the physical environment. For example,

[22] Tumusime Generas Re: Seasonal farming problems.
[23] April 24 2006. Turihabwe Moses. Re: Seasonal farming problems.
[24] April 27 2006. Geoffrey Kacunguru. Re: Crop cultivation & irrigation.

when *"the soils are dry and a dry wind comes which means the water goes then watering must be done morning and evening."*[26]. Irrigation is likely to be applied to high value crops such as tomatoes, cabbages, rice and grapes. Rice irrigation has been encouraged by agricultural extension officers via the use of stiff elephant grass grown locally which is then wrapped into a broom shape and used to flick water from a bucket or can over the crop[27]. These forms of applying water to crops are not considered to be irrigation by smallholders, although they do constitute a form of SSI. Stream diversion and wetland cultivation is commonly practiced in areas with steep terrain where there are perennial streams and wetlands.

Figure 31. Irish potatoes on raised irrigated beds. Water is diverted from a nearby stream.

Tea can provide an important source of income during exceptionally dry periods when there is crop failure as the income obtained means farmers can purchase food. During the last major drought in 1999 smallholders such as Richard Mucunguzi in Mburameizi

[25] April 19 2006. Nora and John Kweyamba. Re: Watering crops.
[26] June 23 2006. Barahm Asiimwe. Re: Irrigation scheduling.
[27] July 24 2006. Charles Kanyagi. Re: Irrigation of rice.

"*used to buy posho from income from tea then sometimes sell goat*"[28]. This highlights the role both tea and livestock have to play as buffers to natural shocks such as drought.

Case studies from selected collection centre areas

Selected case studies from contrasting collection centre areas in the KGTF area are presented in order to elucidate some of the agronomic and socio-economic factors influencing tea production and smallholder livelihoods within the area. Representational diagrams of smallholder plots and homesteads are shown in appendix 9.

Rwambogo

Rwambogo collection centre area possesses the most even yield distribution within the KGTF area and the highest kg ha^{-1} (1996 – 2005). Anecdotal evidence suggests it has a higher rainfall than the collection centre areas close to the KGTF. Soil type in the area is clay loam. Despite residing in an area with high evenness of yield, AB has one of the most uneven yields in the KGTF area as ascertained from individual smallholder yield analysis (Figure 32).

[28] April 28 2006. Richard Mucunguzi. Re: Responses to drought.

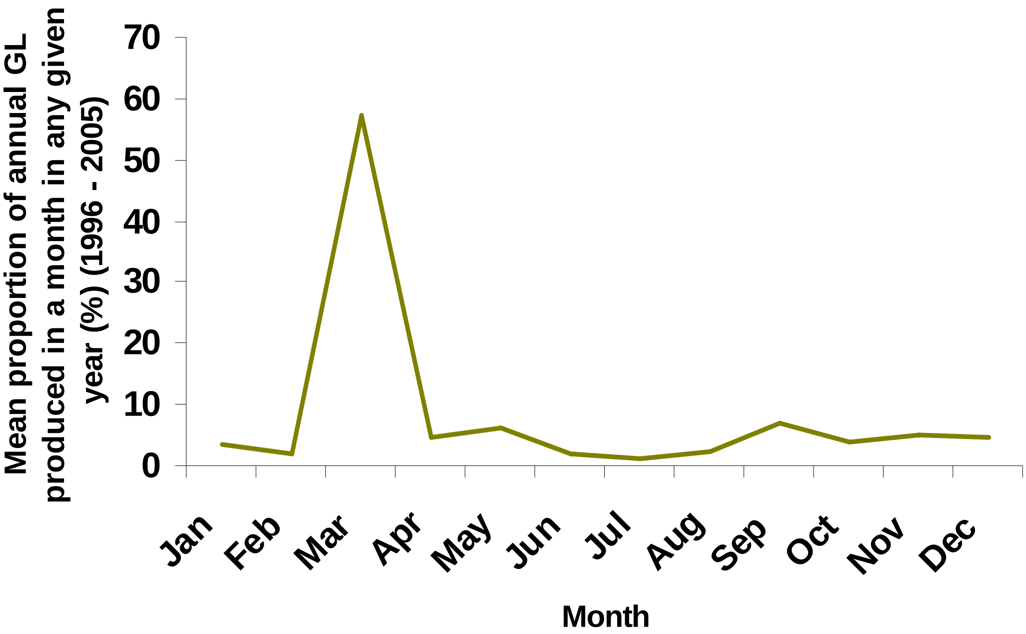


Figure 32. Mean proportion of AB's annual GL produced in a month in any given year (%) (1996 – 2005).

One is rented out to another farmer while the other is abandoned. There are a variety of reasons for this including:

- Fragmentation of land. The furthest plot is approximately 10 to 15 kilometers away. This makes it difficult to manage all the plots especially during peak flushing periods.
- Inadequate establishment of young tea bushes. Two plots consist of young tea bushes between 1 and 2 years old. They have been extensively overrun by weeds and the bushes have not been pruned or pegged down to encourage horizontal growth thus compounding the prevalence of weeds Figure 33.
- Diverse income sources. AB estimates that his main sources of income are from livestock in the form of goats and coffee production. Combined these enterprises bring AB additional income. However, AB's budget shows that his combined income from renting of his tea shamba together with production from his other shambas accounts for 26% of his annual income (140 000UGX) (appendix 5).

A summary of the characteristics of AB's tea shambas and nearby water sources is given in Box 8.

Box 8. Rwambogo collection centre 3 – Murenge.

Farmer: AB	
GPS: S0056 67 771 E029 40 982	
Alt: 1775 m	
Date of observation: 10.06.06, 26.06.06	

Tea shamba characteristics

Plot number	**Size (ha)**	**Soil type (30cm feel test)**	**Crop cover (%)**	**Observations**
1	0.1	Sandy clay loam	80	Fairly good cover no gaps. Some plants with dry tips Tree in shamba Very low – over pruned?
2	0.1	Sandy clay loam	40	50% weeds Gaps in plot Trees in plot Overpruned
3	0.1	Sandy clay loam	90	Good cover. No gaps
4	0.1	Sandy clay loam	20	Overgrown Weeds & beans growing inbetween. Almost abandoned. Steep land Erosion signs where plot meets road

Water resource characterisation

Plot no.	**Distance from Homestead (km)**	**Position of plot in relation to Water Source (m)**	**Type of water source**	**Other crops grown close to shamba**
1	10 m	10 m above	small community pool	Coffee
2	10 m	More than 20m above	same as above	Coffee
3	1 – ½ km	10-15 m above	spring	Other tea farmers
4	2 km	None close	None close but SWC potential.	Millet, beans, maize.

AB lives in an area which although close to a main road is on steep terrain that can be difficult to access. There are several water sources available. A river runs along the valley bottom. Close to this a protected spring is located. However the slope of the land and distance of the river from Murenge settlement make this a difficult resource to access. A community hand dug pool provides the main water source for AB (Homestead and shamba diagram appendix 9a). This also serves livestock and other families in the area. Residents in this area are keen to improve this water source further.

Figure 33. Plot number 2. Weeds growing among tea bushes

Livelihood strategies

The geography of the area undoubtedly affects smallholder asset development. In particular, decreased access to structures in the area such as KGTF and governmental agencies affects this. Although there is a high level of natural capital in the area evidenced by abundance of water sources and land, physical capital in the form of infrastructure can limit smallholders who may have difficulties accessing institutions that could support improvement of these resources.

Bikuto

BC and his family live close to KGTF. Rainfall in this area is likely to be similar to that at KGTF. Soil is a sandy loam type with a top soil layer consisting of a large percentage of gravel and large stones. The Bikuto collection centre is also classed as drought stressed by local staff and farmers. BC's mean yield demonstrates the seasonal fluctuations experienced in the area. He receives 12.5 % of his annual yield in May during the largest flush and only 4.3 % of annual yield in February. His plucking regime during wet seasons is every 7 to 10 days. However, in the dry season this is reduced to once a month.

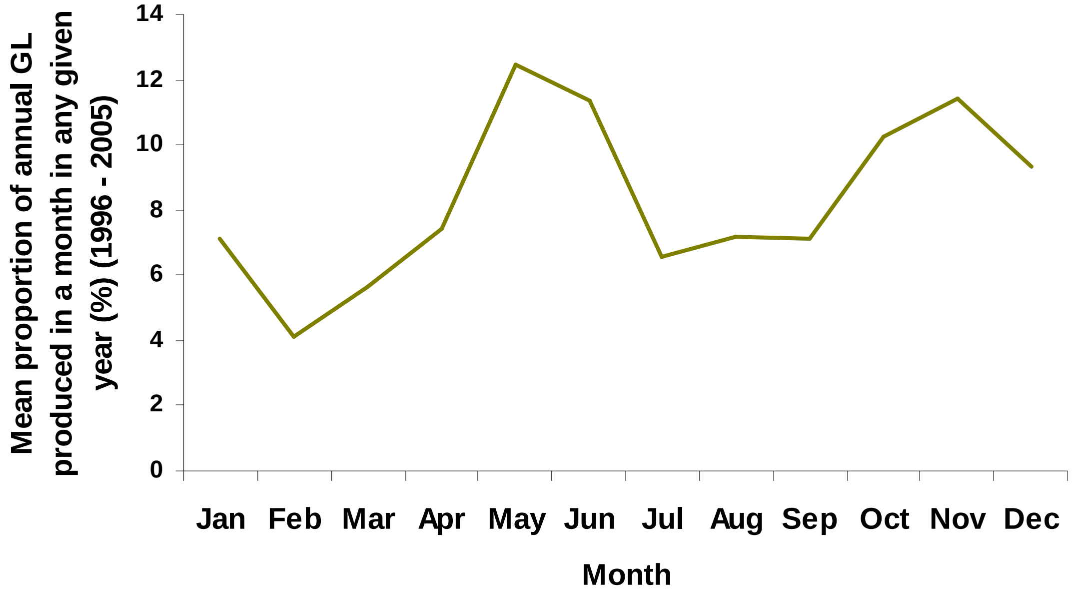


Figure 34. BC mean proportion of yield (%) received each month in a year (based on mean data 1997 – 2005)

This seasonal fluctuation suggests that irrigation may be beneficial in creating a more even yield distribution. A summary of the tea shamba and water source characteristics of BC's homestead and land are given in Box 9.

BC could be seen as a farmer entrepreneur. He is keen to adopt new technologies, take risks and experiment as evidenced by his involvement in several district and nationally

Box 9. Bikuto – Collection centre 8

Farmer: BC	
GPS: S 00 54 16 1 E 0290 38 9 65	
Alt: 1040m	
Date of observation: 21.04.06, 21.06.06	

Tea shamba characteristics

Plot number	**Size (ha)**	**Soil type (30cm feel test)**	**Crop cover (%)**	**Observations**
1	0.4	Sandy loam. Lots of gravel and stones	80	2 mango trees growing within plot. Some of the bushes at the top of Isiah's plot have dry tipped leaves, a possible sign of drought stress

Water source characteristics

Plot no.	**Distance of plot from homestead**	**Distance of plot from water source (m)**	**Type of water source**	**Other crops grown close to shamba**
1	20 m	20 m uphill	Protected spring.	Mango tree

sponsored schemes introducing new cash crops to the area. BC's farming system is varied and he is enthusiastic about adopting new technologies and practices. (Table 12 shows farming enterprises he is engaged in). BC says that markets for these products are not always as readily available as agricultural extension officers assert. For example, BC has yet to gain access to a reliable market for his okra, vanilla or chilli despite being encouraged as part of national agricultural initiatives to grow them. BC hopes that access to national markets will increase, allowing him to access other income sources. BC has participated in several workshops in the area organised by CARE Uganda and consequently practices the techniques he has learnt. These include use of a home made pesticide consisting of *Tephrosia*, red chilli and goat urine which can be used when weed killer is not available on most crops including tea. BC also collects manure and urine from his livestock and has a composting shed.

Table 12. Farm enterprises

Farm enterprises	
Crop	**Livestock**
Vanilla	Rabbits
Chilli	3 pigs
Okra	17 goats
Grapes	17 sheep
Rice	4 cattle
Coffee	Fish
Banana	
Passionfruit	**Other**
Peas	Construction of goat and composting sheds
Cacao	
Tomatoes	
Tea	

BC is keen to improve water supply to his homestead. He has investigated the costs of purchasing a rainwater collection tank from Kabale. However, he was unsure whether the benefits of this would outweigh the costs. BC believes that a rainwater collection tank would "*reduce the time to walk to the spring, it would reduce the time without water and the need to fetch it*"[29]. He is keen to invest in a water storage device to improve his dry season domestic water supply, to reduce labour and time collecting water which can be considerable due to livestock water needs and in order to attempt small-scale irrigation if possible.

According to BC the largest proportion of his income comes from coffee, pig breeding and goat sales. These combined account for 75% of his annual income (appendix 6). However, he would like to increase his income from tea and recently purchased an additional tea plot. As BC inherited his tea from his father and his sister is sponsored in her studies by KGTF and Cafédirect via the double orphans sponsorship scheme BC feels a strong connection to the tea factory and tea production.

[29] 21 July. BC. Re: Roof collection tanks and home water supply.

Although there is a discrepancy between income and expenditure, BC is able to meet his expenses each year. This is in part due to his membership of Kayonza microfinance locally which enables him to withdraw shillings with a payback period of 4 months at 12 % interest. He would be willing to invest in a new water collection technology if a finance organisation could help with loans. Considering the diversity of BC's crop production and his desire to improve supplies of water for domestic and livestock use additional uses for any system must be taken into account. BC has available land above his tea shamba which could serve as a rainwater catchment area.

Livelihood strategies

BC's willingness to take risks and invest in a very diverse range of farm activities has probably contributed to the sustainability of his farm and enabled him to reduce his vulnerability to natural shocks. BC's location close to the KGTF and the main weekly market in Butogota is an advantage in terms of giving him a greater physical asset base via the transport links and local services in Butogota town such as Kayonza microfinance agency thus improving his financial asset base. Ability to invest in new farming enterprises is likely to be both a product of the stability of his farming system and a factor contributing to its success. BC recognises drought problems such as lack of crops and illness as a result of food shortage. However he has *"never been badly affected due to the timing and growth of plants, as the onset of the dry season is the onset of harvesting"*[30]. Undertaking courses in the area and developing his knowledge of farming techniques has undoubtedly given him a greater human capital asset base to draw from. BC is able to save money each month and even contribute to his sister's education in Kabale. In addition to these expenses BC donates milk to smallholders living close to his homestead in return for allowing his cattle to graze in the area. This form of exchange is an example of ways in which social cohesion is maintained thus contributing positively to social capital in the area.

[30] 21 April, 2006. BC re: drought and food shortage.

Itembezo

Itembezo is a collection centre area that isn't ranked as suffering from drought stress by field officer perception. However, it does have an uneven yield distribution (s.dv. 1.76 Table 9). CG and her husband are tea producers in Itembezo. In contrast to AB and BC's production data the highest proportion of GL from their shambas (14.5 %) is produced in January (in contrast to May for BC) while the lowest proportion of GL (3.2 %) is produced in July (for BC this was in February) (Figure 35).

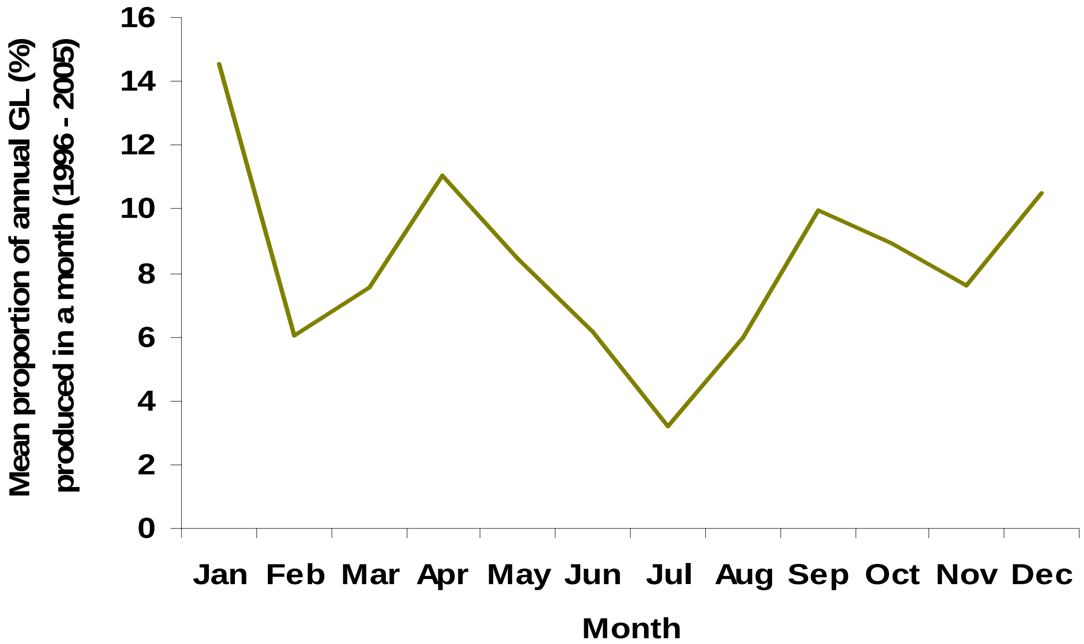


Figure 35 CG mean proportion of annual GL (%) produced in a month (1996 – 2005

Soil and local climatic conditions may be the explanation for the different yield distributions observed. A summary of plot characteristics is given in Box 10.

Box 10. Itembezo – Collection centre 26

Farmer: CG	
GPS: S 0054 987, E029 46 866	
Alt: 1395 m m	
Date of observation:21.06.06, 25.07.06	

Tea shamba characteristics

Plot number	Distance of plot from Homestead	Size (ha)	Soil type (30cm feel test)	Crop cover (%)	Observations
1	5 m	0.4	Clay loam/ Sandy clay loam	80	Fairly good cover no gaps. Some plants with dry tips Tree in shamba
2	10km	0.2	Clay loam/ Sandy clay loam	40	50% weeds Gaps in plot Trees in plot Overpruned

Water source characteristics

Plot no.	Position of plot in relation to water source (m)	Type of water source	Other crops grown close to shamba
1	20 m uphill	Valley marsh/ protected spring.	Mango tree
2	over 1 km distance to valley bottom	spring	Other tea shambas

Specific difficulties experienced with tea include leaf burn on some plants possibly as a result of misapplied fertilizer and lack of knowledge on how to rehabilitate their second tea shamba (Figure 36 and Figure 37).

Like BC and AB, CG obtains most of her income from livestock sales. Tea accounts for 28% of the family annual income (appendix 7). However, tea is an important income source in that its regularity and relative reliability allow CG and her family to plan expenditure. The household has a diverse range of income sources including coffee, pineapple, sugarcane and banana beer and occasionally Charles's pay from logging near Kampala. CG has many debts from medical and social obligations which she manages by monthly restructuring (Box 11). Tea profits are used for debt payments as CG is able to guarantee a monthly payment and her tea shamba acts as assurance of this. This demonstrates the important role tea has to play as a buffer against sudden shocks and expenses in smallholder livelihoods.

Figure 36. Leaf burn on recently pruned bushes.

Figure 37. CG's second tea shamba.

CG would like regular advice on how to manage her tea as pruned bushes are currently suffering from leaf burn and improved access to young tea bushes in order to infill gaps on her second shamba (Figure 36, Figure 37). Nurseries were established but CG states *"today the nurseries are not operating so we do not get the seedlings"*[31]. Although tea provides a regular income for CG she would prefer to irrigate tomatoes and beans if given the choice as they can earn *"100 000 UGX in a season if you get enough"*[32]. CG also feels this would also improve food supply for the family. This supports comments made by other farmers who felt that *"it would be better to irrigate those food crops that are consumed and then irrigate the crops for money"*[33]

Livelihood strategies

Charles's occasional employment with a logging company outside Kampala is a form of temporary migration that might be termed as 'straddling' [34]. He occasionally lives and works in another region in order to provide additional income for the household. A lack of human capital in the form of knowledge with regards to tea management practices and a lack of financial capital in the form of savings and loans means that the family is badly affected when sudden shocks such as illness occur. However, social capital is high and the existence of a self help group and the help that CG is able to seek when paying debts enabling her to "*ask for help from those people who can and then pay later"35* compensate to some extent for the lack of access to services.

[31] August 16 2006. CG. Re: Access to clones & problems with tea production.
[32] June 21 2006. CG. Re: Preference for irrigation.
[33] May 08 2006. James Barihonga. Re: Preference for irrigation.
[34] DFID. (1995) Introduction to SLF. Sustainable livelihoods guidance sheets. Livelihood strategies
[35] June 21 2006. CG. Re: Strategies for coping with drought.

Box 11. Health and healthcare
Smallholders have varying access to healthcare. There are local dispensaries in many areas. However, smallholders may have difficulty accessing them especially if "*it takes 2 hours to walk there…even patients with malaria may be dead before they reach there*" [36]*.* they are not always equipped with sufficient resources such as medical staff and drugs to treat patients. Dry seasons can make smallholders more vulnerable to health shocks as *"there is little yield and so little money. Yet, there are more diseases in this period such as malaria fever"*[37]*.* As a course of malaria drugs can be between 5 and 10 000 UGX obtaining sufficient income to purchase medicines can be a concern for smallholders. At Buhoma medical centre, a high proportion of illnesses diagnosed are a result of water borne infections, malnutrition and micro-nutrient deficiencies caused by a diet lacking in vegetables [38]. These health difficulties impact upon smallholder livelihoods and affect the ability of smallholders to work and so secure income while also leading to significant expenditure for medicines.

Kihinga – Mafuga

Kihinga collection centre covers some of the most remote areas in the KGTF area. This includes Mafuga. It also has one of the most uneven production records of the KGTF area (s.dv 2.21). DE's shamba production follows the same production pattern as the mean collection centre production and has a similar unevenness (s.dv 2.01). Interestingly evenness of production in this area does not appear to be affected in the same way as other KGTF areas. The bi-modal pattern apparent at other centres is not clear here. The proportion of GL received in the first dry season in February remains high. It is only during the second season in July and August that production drops. In contrast to BC and CG, DE receives 4 % of her annual production in August and the highest proportion (10.2%) in May (Figure 38).

[36] April 26 2006. Molly Musevene. Re: Healthcare services in Mafuga.
[37] Ibid
[38] July 23 2006. Dr. Scott Kellermann. Re: Prevalent illnesses at Bwindi forest community health centre.

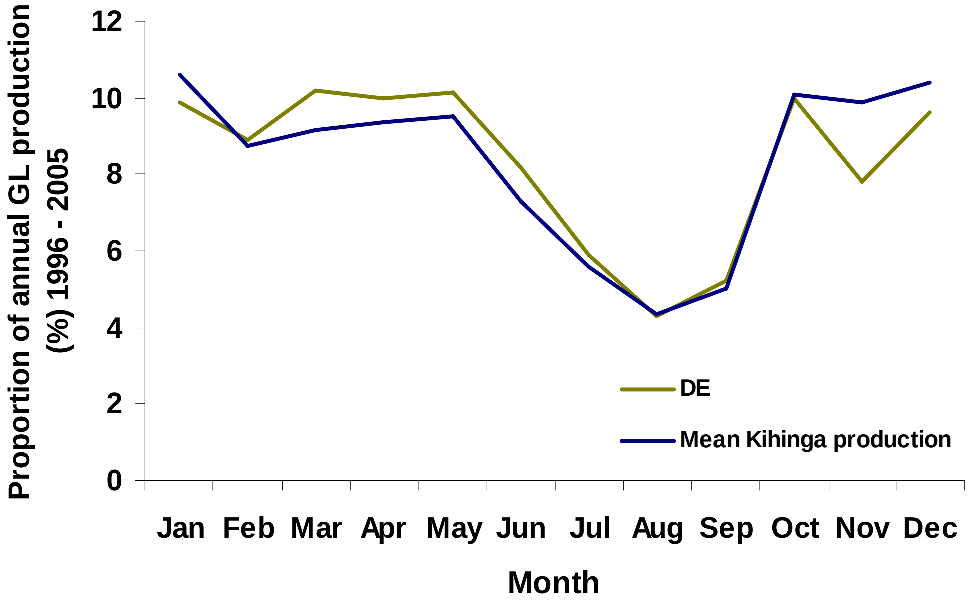


Figure 38 DE. Proportion of GL received as (%) of annual total (1996 – 2005) and Kihinga collection centre proportion of GL production (%) of annual total (1996 – 2005)

This KGTF area receives three collections per week due to what are considered to be low overall production figures. Although at 2132 kg ha^{-1} the mean annual green leaf production at the collection centre is not the lowest in the KGTF area. DE lives in Mafuga which until 2005 did not possess its own collection centre instead. Farmers instead walked a steep 2 hour climb to the nearest centre. Characteristics of DE's shamba and nearby water source are summarised in Box 12.

Box 12 Kihinga – Collection centre 33

Farmer: DE Kakawata
GPS: S01 01 185, E 029 50 290
Alt: 1775 m
Date of observation: 26.04.06, 25.07.06, 11.08.06

Tea shamba characteristics

Plot number	Distance of plot from Homestead	Size (ha)	Soil type (30cm feel test)	Crop cover (%)	Observations
1	Next to	0.06	Clay loam	90	- Heavily pruned during dry season - Vegetation close to border. - Avocado and mango trees in plot.
2	Next to	0.01	Clay loam	90	- Well managed but not even plucking table - Vegetation close to border.

Water source characteristics

Plot no.	Position of plot in relation to water source (m)	Type of water source	Other crops grown close to shamba
1	20 – 30 m uphill	Protected spring.	Mango tree
2	Ibid.	ibid	Other tea shambas

DE has been farming here for 15 years. However, it is only in the last five years that she has started to cultivate tea. The cost of maintaining her shamba is high but DE is committed to improving her tea production as it accounts for 79% of her annual income (appendix 8). However, she is concerned that she does not receive as much advice on tea management as she would like. She pruned her tea shamba in May this year but was not confident that she had the skills to undertake this exercise *"I prune it badly but I don't know how to do it"39.* DE is also unsure of the best time to apply fertilizer and herbicide. Difficulties accessing inputs compound these problems. As DE's shamba is registered in her absent husband's name she is not formally registered and thus cannot

[39] April 24 2006. DE. *Pers.com.*

request inputs herself (Box 13). The collection centre area also frequently receives inputs later than other centres.

Box 13. Gender
The majority of tea shambas are owned by men. However, 14% of the smallholder producers at Kayonza are women (MacMillan and Kumar, 2005). However, this figure is unlikely to represent the true number of women who are the sole managers of tea shambas or who work on tea shambas as shambas are more likely to be registered under male family members due to the predominance of male inheritance.

Many of the prunings from her shamba have been removed as they make good kindling for fires. Forests close by are predominantly pinewood which is sold for timber 5 to 10 years after planting. There are also eucalyptus woods in the area. However, these are often privately owned.

Figure 39. DE's tea shamba. Coco yams can be seen in the foreground and an avocado tree grows in the middle of the shamba.

DE states that food security is a problem for her and her family as her total land area under cultivation is not enough to subsist on. DE grows sorghum, beans, potatoes, yams avocado and passionfruit (Figure 39 shows DE's tea shamba and some other crops). The passionfruit and yams are located in the vicinity of the homestead while other crops are grown on the same plot of land. However, DE would like to be able to grow tomatoes and beans under irrigation if given the choice in order to secure food during the dry season and in order to sell any excess produced. DE's lack of access to human capital in the form of knowledge with regards to tea production compounds the lack of control she has over her tea production and her feeling that despite the fact *"I would like to end my poverty… there is nothing I can do, even if I want salt I cannot buy it"*[40].

In addition to the above highlighted aspects of tea production, tea may serve as a resource in old age or retirement (box 14).

Box 14. Tea as a supporting asset in retirement and old age

Jovia's tea shamba in Buhoma. Her son's home is In the distance.

Tea can support smallholders in retirement and old age. Jovia Karambuzi lives close to Buhoma near the tourist entrance to Bwindi Park. She started growing tea 30 years ago and still cultivates tea and matooke but relies on her extended family to supply other food. Her tea income is contributing to the cost of building a new home. However, *"at my age it is difficult to pick the tea. I don't have the energy"*[41]. The proximity of this community to the Bwindi forest entrance means that smallholders obtain some benefit from the tourist market locally *"when visitors come we can get a market for the matooke and can weave baskets to sell for money."*[42]
Charles worked as a driver at the KGTF until 1972 when he retired and took up full time tea cultivation as *"it's tea which has earned me an income for a long while"*[43]. Similarly Jack Turygyendo decided to invest in tea after retiring from work in a local hospital.

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[40] April 26 2006. DE Kakawata. Re: Farming difficulties.
[41] July 22 2006. Jovia Karambuzi. Re: Sources of income.

Factors perceived to affect tea yield & quality

Physical environment

Constraints of the physical environment include terrain and geographical position of KGTF. The impact of factors such as climate and soil on yield has been discussed. In dry seasons *"When there is lots of sunshine the tea dries up and there is no production at all. The crops are dry and the family stays in misery"*[44]. The limited tea production experienced by smallholders in dry seasons can be compounded by crop failures or lower production of food crops.

The terrain of the KGTF area also impacts upon tea production and costs. *"We are the furthest in the country so we buy services and other tea machinery and inputs at a relatively high price compared to other tea factories"*[45]. As the quote demonstrates the geographical location of the tea factory has an impact on the costs the factory incurs such as buying services or diesel. As the district is not yet on the national power grid the factory must buy diesel not only for collection lorries but also to power generators to provide domestic electricity, power tea processing machinery and pump water from the nearby river to supply the factory and worker camp requirements. These costs are reflected in the lower prices smallholders receive for their leaf in comparison to other tea factories. Leaf is also collected late in the afternoon from smallholders and it may take the whole day for a collection lorry to pick up leaf meaning that factory production often stretches long into the early hours of the next morning.

The factory acknowledges that the quality of leaf that it receives differs according to area with higher altitude areas producing better quality tea but in smaller amounts than that received from lower altitude areas. The lack of standardisation in quality of leaf received is a constant problem for production staff who must process green leaf to the

[42] *Ibid.*
[43] July 24 2006. Charles Kanyagi.
[44] April 24 2006. Tumusime Generas. *Pers.com.*

best of their abilities. As better quality leaf tends to produce finer graded and thus higher priced tea the final product rests very much on the conditions in the smallholder field.

Tea as a business

KGTF management and extension officers along with local government officials view smallholders complaints as a product of lack of education and understanding. They cite a problem of smallholders refusing to view tea as a business *"Our smallholders have not yet looked at their farms as businesses. There is that missing link"*[46].. Business management for tea may be a constraint. However, it may be the risk involved in focusing on on only one crop which limits smallholder investment as opposed to lack of business acumen.

There is perceived to be a problem with smallholder food production within the area. In addition to this smallholders are criticised for buying food instead of growing it. However, a greater focus on tea production on a large scale would necessitate purchase of food as limited resources become focused on cash crop production. Factory management and local officials perceive lack of home food production to be due to the previous reliance that the district is seen to have had on smuggling and cross-border trading as a means of income. This trade with the Democratic Republic of Congo (DRC) is thought to have led to an over-reliance by the local population easy money[47]. A change in the previous high prices that could be gained for coffee in the DRC and a government crackdown on this trade are given as two reasons for the decrease in reliance on this in recent years. Nevertheless, it is still viewed to have had an effect on agricultural production locally accounting for a desire by smallholders to *"make money*

[45] April 20 2006. Marcel Asimwe. *Pers.com.*
[46] July 2006. *Anon. Pers.com.*
[47] *Ibid.*

fast"[48] and demonstrate limited commitment to tea production. It is not possible to ascertain to what extent this is true and how widespread cross border trading was and still is.

Despite the perception that many smallholders spend most of their tea income on food for the family instead of growing it themselves smallholders interviewed during the course of this research seemed to spend a greater proportion of money on education for their children and healthcare. Those that spent money on food cited poor harvests and a lack of labour to help on the farm as reasons for purchasing food. Tea was often cited as the most important income source by smallholders even if it didn't account for the greatest proportion of income. However, smallholders were still concerned that tea did not bring a sufficient income when costs of production were subtracted; *"A long time ago we used to sell a kg at UGX 120 and buy fertilizer at UGX 20 000. But today we sell our tea at UGX 160, but we're buying a sack at UGX 40 000 so that's doubled"*[49]. Although this quote demonstrates that costs of fertilizer have increased, it also shows that, assuming production from a shamba remains the same smallholder profit from tea has also increased. It may be that farmers perceive costs to have increased as they view their benefits to have reduced in comparison to past advantages of tea production. Shareholders complain that they received greater profits from their shares in the past which is undoubtedly true as EU subsidies to the factory meant that field officer salaries and fuel costs were heavily subsidised or paid for. Removal of these subsidies has affected shareholder profits. In addition to this some farmers commented that they received gumboots and spray pumps as gifts from the factory at Christmas [50]. These gifts have not been received in recent years.

[48] July 2006. Field officer interview.
[49] June 21 2006. CG Re: Benefits and problems with tea cultivation.
[50] July 20 2006. Paul Bitakaramire & Charles Tiragana.

Current factory strategies for improving green leaf production

The factory has adopted strategies in order to try and increase green leaf production among smallholders. Most strategies focus on improving production from large hectarage producers who the factory etimates account for a large percentage of their production. Calculations based on KGTF database information show that based on total Kilogrammes produced from 1996 to 2005, producers with hectarages ranging from 2 to 47 ha (with a mean of 5ha) produce 11% of the factory's total GL delivery. A recent target meeting with large hectarage land owners with a view to ascertaining reasons for lower production and abandonment of plots highlighted the need for:

- Timely delivery of fertilizer.
- An increase in availability of fertilizer.
- A re-introduction of payment advances enabling smallholders to collect an advance payment after the 15th of each month based on leaf already provided for the factory.
- An increase in the price of green leaf from 160UGX (Ugandan shillings) per Kg to 170UGX per Kg together with a 30UGX per Kg increment paid every three months.

Additional incentives include the introduction of a best improved tea shamba competition within the area with a 1 million UGX prize for the winner. The top 15 smallholders selected by field officers as the most improved or best producers in their area won gumboots, spray pumps and herbicide. The extent to which these incentives are likely to improve tea production is unclear. Certainly several smallholders were unhappy with the price they received for their green leaf which they were aware was much lower than other tea factories such as Igara[51]

"One of the problems we face is that the tea is being bought at a lower price and we would prefer that the tea is bought at a higher price…here we are paid 160UGX. If we use labour it is 60UGX per kg which takes the earnings."[52]

[51] The increase in payment for GL brings the amount received by farmers close to that received at other tea factories. However, it is not clear what the reasons for lower payment here are. Costs of fuel and maintaining generators are cited as factors affecting this.

[52] June 12 2006. Anon farmer Rutenga. *Pers.com.*

Tea production and investment risk

Although tea represented a significant source of income for local smallholders, the small size of most tea shambas precludes all but those with the largest hectarage from devoting their farmland solely to tea. Smallholders may also be cautious to invest everything in tea as Fudeli explained *"If it is a cow or a sheep at least we can slaughter it if there is no money or no food to eat but if it is tea what can we do?"*[53]**.** In order to ensure sustainability of their farming system smallholders rely on a diverse range of income sources. These may vary according to geographical area, local industry, skills base of the household and resource availability. For example, smallholders in the proximity of Bwindi Park may sell handicrafts to tourists or have an additional market for their livestock and crops with local restaurants. In addition to tourism regional industries include brick making, logging in Mafuga and construction. Industries found throughout the region include the production of homemade fertilizer, warangi (alcoholic drink made usually made from fermented bananas or pineapple) brewing and the sale of labour either as and individual or collectively via organisations such as women's land work groups.

Local cash crop market:

Cash crop prices vary according to season and availability. Rutenga sub-county is a high altitude area on the only route from Kanungu district to Kabale. High rainfall ensures that potatoes, peas and cabbages tend to be available in this area for a longer period than other parts of the KGTF area while a regular transport route ensures a wider market for these goods. On the same route there is a well established point for selling and buying banana, matooke and passionfruit. This permanent roadside establishment is not subject to the market tax that vendors must pay and so offers less risk for producers who must recoup these costs in their sales. Vendors may also travel some distance to reach a market it is important that the vendor is able to recover the cost of their travel in the goods they sell. This is an additional risk for smallholders

Prices observed for crops at the local market in Butogota and Kihihi during the course of this resarch are shown in appendix 4. Although prices of some goods such as matooke remain fairly constant, crops such as beans may be subject to seasonal price fluctuations. As smallholders rely on rainfed production, without application of additional water they are unable to pace the crops they grow to maximise the price they receive for them as planting and harvesting seasons are determined by the climate. Smallholders with storage are at an advantage in being able to store a particular crop such as rice, maize or beans until prices are more favourable.

Some smallholders may focus a proportion of their production on high income crops such as tomatoes, onions & aubergine which fetch higher prices than staple food crops such as maize. Application of water to these crops is familiar to smallholders. The high price these products fetch at markets is probably due to the fact they are not extensively cultivated for sale as families tend to grow what is required for the household. In addition to this tomatoes and aubergines are pest and drought susceptible. At Buhoma a project is currently being established with aim of cultivation of high price cash crops for supply to tourist camps at Bwindi forest [54] (Sandbrook, 2006). If this is successful there may be potential for growth of this market to include supply of fish and livestock as the tourist market in the area grows.

Prioritisation and Risk

Smallholders must decide how to allocate time and resources to agricultural production. With limited land resources they face difficult choices when deciding whether to invest more time and energy in high value crops which can bring higher returns but at a greater management investment and greater risk of investment failure. Issues of prioritisation of resource use also include strategies for managing risk associated with farming. Diverse income sources and farming practices allow risks to be balanced. This can be seen to be

[53] June 23 2006. Fudeli Byamugisha. *Pers.com.*

a strategy for coping within a social and physical environment in which smallholders are at risk of shocks that can threaten their livelihood sustainability. Shocks may come in the form of

- Climate variation such as drought or hail damage which can severely affect tea and other cash and subsistence crops. Seasonality of crop production means that smallholders need strategies to cope with seasonal changes.
- Changes in access to inputs for production which will have a knock on effect on yields and so income.
- Human health shocks. Unexpected medical needs can lead to significant expenses for smallholders. These may be seasonal as is the case with malaria.

Summary

The smallholder farming system is diverse and tea is just one component in its overall structure. SSI and SWC techniques are currently practiced within the KGTF area. Case studies demonstrate some of the agronomic factors affecting smallholder tea producers as well as factors that affect smallholder asset distribution. Smallholders may employ a variety of strategies in order to ensure sustainability of their livelihood. Tea is an important aspect of livelihood security. The significance of tea can be summarised in the following ways.

- Tea as insurance. The longevity of tea shambas and their resilience means that they are considered to be a safe investment despite the misgivings some smallholders may have with regards to returns
- Tea can be a buffer to reduce smallholder vulnerability. This is evidenced in the way in which smallholders can utilise tea as a guarantee on loans and the predictable income it supplies.
- Tea as inheritance. As tea is inherited there is an emotional connection to tea production with many older tea producers expressing pride in their ability to survive the times much as their tea shambas have.

[54] December 2006. Chris Sandbrook. *Pers.com.*

Attitudes to irrigation can be summarised thus:

- Smallholders may perceive crops other than tea to be more worthwhile irrigating in advance of tea due to their ability to provide instant income and contribute to food security.
- Fragmentation of land is common. This could pose management & supply problems for an irrigation system. Individual plots carved out from one area is another feature due in part to inheritance systems which split land between different family members (appendix 9 shows diagrams of case study plots, giving an indication of the logistical difficulties associated with plot layout and fragmentation of land).

Yield

- Smallholder production records support yield analysis of collection centres.Yield evenness may vary due to factors other than drought stress as demonstrated by individual yield patterns.
- Yield is viewed to be affected by climate and smallholder dedication to tea production.

Smallholder attitudes to tea production and irrigation possibilities are reflective of their diverse farming systems and need to minimise risk in agricultural production.

5 Water management options for smallholder tea producers.

This chapter synthesises climatic, yield and agronomic data in light of smallholder livelihood vulnerability and technology options for tea and food crop production.

5.1 Context

As the previous chapters have demonstrated there are several factors influencing smallholder vulnerability within the KGTF area. The characteristics of the wider context within which KGTF operates also have a significant impact on smallholder livelihoods and the selection of and adoption of water management technologies to support tea production and smallholder livelihoods. These include the physical environment which impacts upon livelihoods in the area via soil characteristics, seasonal and annual climatic patterns and unexpected climatic shocks such as hailstorms or uncharacteristically dry seasons. The location of water sources and access to fuel sources are also aspects of this physical environment. Current infrastructural problems include lack of transport and the absence of a connection to the national electricity grid. Lack of infrastructure affects the ability of local markets to access goods. This has the potential to impact upon availability of irrigation technology as mechanisms for supply of replacement parts and technological services are key to the implementation of a system. The presence or absence of agricultural markets at a local, national and global level has an impact upon the local environment and is also a product of infrastructure. This influences decisions on what and when to irrigate and the potential sustainability of any irrigation system. KGTF and its smallholders are connected to a broader economic context of the global tea market and so influenced by global market forces which affect this market. This direct link to the global economic market means that there is a reliable market for KGTF tea. However, aspects of this market such as weekly tea auction prices which can fluctuate unpredictably will have a direct impact on smallholder farmers.

5.2 Site specific context

Site specific factors affecting smallholders and the tea and the farming system can be framed within the sustainable livelihoods framework (SLF) assets categories. Access to these assets may be affected by transforming structures and processes which may be in the form of national and local government policies and local organisations such as KGTF.

Natural capital

Natural capital is a crucial aspect of livelihood security within the KGTF as it is upon this that tea production and food security rest. However, it is also the natural environment which can threaten livelihood stability through seasonal shocks caused by climate.

Land

There are an average of 164 people per km^2 (Kanungu District, 2006b). However, this is variable within the KGTF area with areas such as Mpungu possessing 117 people per km^2 (Kanungu District, 2006b). The district government estimates a mean population growth rate of 2.1% per year (2000 – 2005) and predicts that land degradation will increase in the area (Kanungu District, 2006b)[55]. Most land in the area is held via customary tenure arrangements[56]. Tea ownership is registered with the KGTF although this is also a customary land tenure arrangement. The 1998 land act in Uganda made provision for land tenure and implementation of registration of ownership at a national, district and sub-county level (IPTRID, 1998). However, in practice changing land tenure arrangements is a long-term process. This impacts upon selection of appropriate technologies for use in the area as those sharecropping or renting out land may have less

[55] August, 2006. Pers.com. Jackson Saturday. Kanungu District Population Officer re: population growth.
[56] There are four main land tenure systems, customary, freehold, leasehold and mailo. The most common is customary tenure dating from pre-colonial days (IPTRID, 1998). This is an unformalised system of tenure and few smallholders are able to afford to formalise their land ownership arrangements due to the financial costs involved. This may cause disputes with regards to land inheritance. Some individuals in Kanungu district also have freehold tenure of land.

incentive to invest as benefits will be split in two. According to residents in some areas such as Rwambogo costs of land have increased as land close to the Bwindi forest is prone to invasion from pests such as baboons and so there is demand for that which is not close to forest boundaries. Smallholders may also practice sharecropping on other farmers land.

Soil type

The different soil types within the KGTF area, sandy loam, clay loam, sandy and sandy clay loam will affect available soil water and so impact upon yields within the area. In some areas smallholders are also concerned about soil erosion. This is the case in Mpungu where Geoffrey Mutuma who has been a tea farmers since 1969 explained to *"because the land is hilly and steep when it rains there is erosion and the soil is washed off*' [57]. Evidence of erosion was observed both on tea plots and on other agricultural land (Figure 40).

Figure 40. Sheet erosion on steep hillside in Mpungu (alt.1750)

[57] June 23 2006. Geoffrey Mutuma. *Pers.com.*

Rainfall

Natural capital assets are affected by geographical rainfall differences. Rainfall can vary across a small geographical area as a result of altitude, vegetation cover and terrain (Brutsaert, 2005). This is the case in the KGTF area where rainfall amounts were shown to vary between two sites in the KGTF area (Buhoma and Ntungamo). This may have an impact on tea and other crop production. Climatic differences such as annual total rainfall and distribution can take the form of natural shocks when they negatively affect crop production and consequently smallholder vulnerability as may currently be the case within the KGTF area.

Physical capital

Physical capital such as road and transport infrastructure varies within the KGTF area. This is particularly evident in areas located at high altitudes which are frequently the furthest from the tea factory site. Areas such as Rutenga, Ruhija, Kihinga and Mburameizi may receive inputs later than other areas. However, even those closer to the factory may be affected as a farmer in Nyarurambi (20 km distance from the factory, alt.1340 m) explained *"if we could get fertiliser on time then we could apply fertiliser very early such that when the seasonal drought comes we would have harvested much. But sometimes there is a delay of fertiliser which affects us much"*[58]**.** However, labour demands are such during a flushing period that some farmers are unable to find enough labour to pluck all the leaf on their shamba.

Access to water varies across the KGTF area due to available infrastructure. Water sources and technologies in the area include those which are improved such as protected springs, gravity water taps, rainwater collection tanks and boreholes aswell as unimproved sources such as unprotected springs, rivers and streams (Government of Uganda, 2005; Henson, 2006). Smallholders may be physically or financially constrained in terms of their access to water resources. Where gravity water supply is

[58] 24 July 2006. *Anon. Pers.com.*

available monthly user fees were found to vary from 100 UGX (Rugeyo) to 500 UGX (Buhoma) per household. Consequently, some smallholders chose not to use gravity sources. The potential user costs for irrigation water supply are an additional consideration in the implementation of an irrigation system.

Geographical constraints in access to water supply may include the time it takes to access a water supply. Distance or terrain (such as the slope of the land) may affect the time it takes to access water (see appendix 9 for some estimated distances from homestead and shamba to water source). Women and children interviewed during the course of this research reported spending as much as 4 hours a day (although a mean time is 30 minutes) collecting water for domestic use (Box 15).

Box 15. Access to water

In Ruhija, the highest collection centre point in the area at 2080m, tea cultivation is seeing a resurgence. Jotham, the field officer for the area tells me that people are keen to grow tea here. However, Ruhija's position on the border between Kanungu and Kabale means that it feels isolated when it comes to basic infrastructure. This is reflected in access to water. Villagers are unhappy with the inconvenience water collection presents them. A rainwater collection tank has been fitted to the leaf collection centre roof. However, the roof is not adequate to collect the amount of water needed for the village and so the tank often becomes dry before the end of the rainy season as "there are very many people exerting a lot of pressure on it" (April 28 2006. Benon Twehikire. *Pers.com*). Consequently, villagers make a 4km return journey down near vertical slopes to the valley bottom to reach one of the two rivers which surround the village to collect water. Tea shambas are also located in the valley bottom and the terrain here makes movement from home to shamba to river and green leaf collection point tiring work especially for those who live in settlements located on the other side of the valley several kilometres from Ruhija.

Transport infrastructure is limited. Roads within the KGTF area are not tarmac covered and consequently road maintenance is a continual exercise with roads that have been repaired during the dry season rapidly deteriorating during the wet season. More remote areas in the KGTF area may face continual difficulties in obtaining and maintaining culverts to divert water from road surfaces or in order to maintain roads that the district councils does not. Affordable transport is available on market days when extra pick up trucks operate across the KGTF area enabling transport to major trading centres such as Kanungu, Kihihi and Butogota on market days. Bus services also operate between major towns in the area en route to Kabale or Kampala. However, this is expensive in comparison to pick up truck travel. Inadequate roads and wet season inaccessibility can also affect green leaf collection. During "*the rainy season it is hard to get down,* *sometimes the leaf collection truck gets stuck. They should construct a better road so that the truck can come right up to collect the tea"*[59] The fairtrade premium committee support for funding basic infrastructure improvements in road maintenance can have a great impact upon smallholder access to the tea market. This is evidenced in Mafuga where the creation of a road for tea collection trucks in 1999 meant that farmers no longer had to walk 2 hours to the nearest collection centre. However, accessing tea collection centres may still be a problem for farmers living some distance from a collection shed such as Barham who lives in Karambi (alt.1540 m) *"I pluck for 4 hours and then walk for 2 hours to take it to the centre. It's a 2km distance but with carrying it takes longer"*[60]**.** This highlights the problem many smallholders still have in accessing available markets for their goods.

Human capital

Knowledge, skills and practices in relation to tea production are important to the way in which smallholders may engage in tea production. Current field officer services are overstretched which inhibits dissemination of information. Smallholders may be aware of the shortcomings in their knowledge but have no access to the tools to change this *"I prune it [tea shamba] badly and so the stumps often dry up"*[61]. The use of demonstration gardens and activities encouraging improvement of badly performing shambas may prove useful. Information could be disseminated by utilising existing civil groups such as locally organised women's self-help groups or encouraging creation of local NAADS[62] tea farmer organisations may help this dissemination of information.

[59] 20 July 2006. Paul Bitakaramire. *Pers.com.*
[60] June 23 2006. Barahm Asiimwe. *Pers.com.*
[61] April 26 2006. DE Kakawata. *Pers.com.*
[62] NAADS is currently encouraging formation of farmers groups specific to different agricultural enterprises. Rice farming and bee keeping groups already exist in the district. However, tea groups have not been able to be considered for support from NAADS until recently. As NAADS is currently researching SSI and SWC possibilities the organisation offers a good opportunity for collaboration in the area of tea and management.

The district records 42 % absenteeism in schools during farm harvesting periods (Kanungu District, 2006b). More even tea yields could contribute towards reducing this peak labour requirement for tea production. Access to education for children may be limited by labour requirements on the tea shamba. Although the estate does not employ child labour, smallholders may rely on family labour in order to pluck tea especially during flushing periods [63].

Social capital

Social obligations such as bride price can be seen as structures enhancing social cohesion. However, they can also place constraints on families who are unable to meet the financial obligations these entail.

Smallholder farming groups and working co-operatives such as the women's groups which exist throughout the KGTF area demonstrate that there is a high level of social capital (Box 16). Farmer groups which tend to be organised and led by men (although this is not exclusively the case) may be linked to NAADS and so able to access resources and advice via this structure. However, women's working groups and informal savings groups are limited in their ability to access outside organisations and build internal capacity. As many women, although not formally registered may manage or work on tea shambas their understanding of tea production is important to the success of crop production.

Box 16. Self-help and savings groups

The Kyandago Backyara Kureberaho women's group in Itembezo was formed in 2000 and currently has 17 members. The group owns a cow and also collectively runs a banana plantation which is shared amongst 10 families. They also undertake tree planting. Members contribute to the group and every 1 to 2 years a member receives livestock in the form of a calf when their cow reproduces. The group aims *"to work together to empower women and find ways of helping each other."* (August 19 2006, CG Tweheyo. *Pers. Com.*)

[63] August 2006. Bernard Tindiwegi. *Pers.com.*

In rural sub-Saharan Africa it is estimated that 31% of households are headed by women (Chancellor, 2002). Van Koppen suggests that to know whether women's role in agriculture is a decision-making one or a predominantly labour supplying one can help with assessing the potential impact of irrigation on women's activities(2002). However, as examples from within the KGTF area demonstrate, gender roles may change within the agricultural cycle of farming activities aswell as with the age of the household and its composition (Bastidas, 1999). Women may have responsibilities and tasks such as childcare which affect their use of a technology. Within the KGTF area, women are frequently responsible for water collection and distribution within the household. Therefore, they are likely to play a significant role in use of irrigation water.

Financial capital

Financial services

Financial services are available in the form of informal locally organised savings groups and in large towns formal microfinance services are available. Locally organised co-operatives tend to be restricted in numbers and limited in their access to wider strucutures meaning that their ability to act as savings schemes is limited. Access to micro-credit is geographically determined as micro-credit and loan organisations such as Kayonza microfinance are limited to the main towns of Butogota, Kanungu and Kihihi. Therefore, investment in these schemes tends to be undertaken by those who live in close proximity to the organisations. Access to microcredit may be crucial to the uptake and development of any technology in the area.

Livestock

Financial capital takes many forms within the KGTF area. Capital may be held in assets such as livestock. Within the KGTF area this may be in the form of goats, cattle and chickens or land. Although these may be viewed as savings they also constitute a signficant income for some smallholders especially if they are located within easy travelling distance of markets in areas close to the tea factory such as Bikuto and Rwambogo.

Tea

Tea can be seen as financial capital as it constitutes a form of investment or insurance within the KGTF area. A tea shamba may be hired out in order to minimise labour demands on a household via the practice of sharecropping which Bosco Mugarura described thus, "*this is the system where the owner gives me the tea garden and the owner says 'you give me a proportion of the money made or kg of tea'. Payment depends on how many kg are produced but [I give him] about 30% of the production*"[64]

Although affected by drought, tea is a robust perennial crop, able to survive if not generate income during dry periods and so remains a constant asset unlike land on its own which may change value according to development. Many smallholders also rely on other income sources in addition to tea. For this reason, it is not always seen as the most profitable investment for them as changes in markets for other crops such as coffee or rice may make them seasonally more profitable than tea. Farm records are not often kept and so it is difficult to ascertain the change in proportion of income to expenditure in the economics of tea production.

5.3 Livelihood shocks and constraints

Social expenses

Social obligations such as providing food for religious celebrations or bride price for a marriage can place financial and asset constraints on families.

Health

Health shocks may limit smallholder ability to maintain tea shambas and place additional financial and social constraints on the household. HIV/AIDS is an underexplored phenomena in the district as testing rates are low and there is currently no policy of screening children whose parents have died from the illness. The stigma attached to the illness compounds the lack of structures and support available to deal with it. Consequently, many families caring for HIV/AIDS orphans or with relatives who have the illness suffer in silence. The extent to which this affects smallholder tea producers is not clear (Box 17). Illness may also be seasonal in nature. For example, malaria frequently occurs in the months following the heaviest rains such as April and May and October and November. This has an impact upon labour availability when planting activities are taking place.

If an irrigation system involves the presence of open stagnant water bodies it has the potential to affect public health via the increased risk of schistosomiasis and malaria (IWMI, 2002).

Box 17. Strategies for managing sudden shocks

CG and her husband live on the slope of a small valley near Itembezo a trading town in the North East of the KGTF area. At 48 CG has recently seen the marriage of her eldest son – a great cause for celebration but also leaving the family with a bride price debt of 150 000 UGX in addition to livestock donations which the family have made to their daughter-in-laws parents. CG and her husband also recently took in CG's sister's four young children who are double orphans as a result of HIV/AIDS. In addition to this CG's son recently fell ill, she paid for his medical bills and transport to and from the hospital located 40km away. However, his illness has continued resulting in mounting costs. CG's husband works occasionally for 3 month periods for a logging company in Bunyoro or Masindi districts to help boost the familiy's earnings. Howewver, CG must also employ other strategies in order to manage the family expenses. These include "bringing the children back from school or I can also buy on credit. I might go to a shop and then pay at the end of the month when the factory has paid" *(Pers.com Aug.18, 2006)*. CG and her husband's position as tea smallholders can serve as a form of guarantee on expenses within the community. CG may also make tea management decisions as a result of cash shortage "I used to get inputs. I spend a lot on tea with round up, fertilizer & pangas & sprays. I can't always afford to buy it so sometimes I leave it" (*Pers.com Jun. 21, 2006)*

Climate and Seasonality

The natural environment may produce climatic shocks such as unexpected rainfall patterns or isolated incidents such as hailstorms which can negatively impact upon smallholder livelihood sustainability. In the case of tea this is demonstrated in the variability in seasonal and annual rainfall patterns and their impact on tea yields.

[64] May 6 2006. Bosco Mugarura. *Pers.com.*

Crop diseases and pests

When Kanungu experienced coffee wilt in the year 2000, bushes across the district were affected contributing to the collapse of the coffee co-operative thus destroying the infrastructure of an existing market. As a result, some farmers decided to increase tea production. Pests may also cause unpredictable shocks in smallholder livelihoods. These may include varigated grasshoppers, potato blight and mammals. For example on land *"near the [Bwindi] park zone…. crops are destroyed by wild animals"*[65].

Access to markets

Access to additional markets can minimise the impact of shocks on livelihoods. Tea provides access to a reliable market and some level of stability in terms of regular income. However, other markets may be seasonal in nature and see fluctuation in prices for goods and availability of produce as demonstrated by seasonal market prices for goods such as beans (appendix 4)**.** Other informal markets for goods may exist which impact upon tea management and smallholder income (Box 18).

Box 18. Informal markets and inputs

Informal markets also exist affecting current tea production. Fertilizer and pesticides may be sold informally as occurred on a wide scale in 2005 when outside buyers were reported to have targeted smallholders. However, it is more commonly undertaken in the local market or privately between individuals. Fertilizer is often sold at 35 000 UGX and pesticide at 12 – 15 000 UGX (in comparison with factory prices of 42 000 and 12 000). The price at which these inputs are sold is lower than the price at which smallholders purchase them on credit from the factory. This may seem inconsistent considering the fact that 60 UGX per Kg of tea supplied are then deducted by the factory from smallholder payments each month in order to recoup costs. This means that a smallholder may remain in debt to the factory for several months or years if they are unable to pay back their credit loan. However, smallholders can circumvent factory payments by selling leaf via another farmer number. Pesticide is no longer sold on credit from the factory and there are plans for the creation of a co-operative fertilizer distribution circle which will take financial pressure from the factory although may not resolve the underlying reasons for informal input.

[65] . April 24 2006. Stephen Bitasimwa. *Pers.com.*

Structures and Processes

Water policy and local government

Decentralisation of water services since 1999 has seen increased private sector involvement and local government control of water. Lack of community consultation in order to ascertain water needs is seen as symptomatic of this (Barungi et al., 2003). Although water user committees are established with each project to *"ensure there is participation of the whole community in the operation and the maintenance"*[66]of projects in practice these may not always reflect natural co-operative units in a community. For example, a gravity tap in Mburameizi has remained out of use for several months as it required a spare tap. Instead, the community walk a distance of 5 km to a nearby protected spring[67]. As some members of the community harvest rainwater or use protected springs the gravity tap resource is not viewed as a priority. Utilising existing co-operative units or developing individual water supply for irrigation is an important consideration. In contrast, within Kihinga the community instigated the creation of protected springs and contributed labour towards their creation and upkeep. Residents questioned considered these resources to be well maintained. However, any irrigation system would require consideration of how the system might be managed whether collectively or at a household level.

There may also be a lack of clarity in relationships between local government or donating agencies. Communities may feel isolated from governmental agencies and see a lack of maintenance of their water facilities as symptomatic of this. Local government resources are limited and therefore, focus tends to be on meeting targets and expanding coverage to fit national objectives. As construction and operation of systems is contracted out to the private sector, technical support and capacity building for long-term management of schemes by communities has been lacking. How to address capacity building and technical support for an irrigation scheme in the KGTF area is a consideration in developing this resource in the future.

[66] 11 July 2006. Emmanuel Asiimwe. *Pers.com.*

5.4 Possible technologies

Technology Requirements

Criteria for technology selection must take into account possible positive and negative livelihood outcomes from any intervention. The following list is modified from Hudson (1992) and Underhill (1990). A technology;

- Should offer quick benefits
- Should offer a high rate of financial return. An increase of not less than 50 – 100% in order to encourage uptake.
- Should ideally be based upon an existing technology or practice.
- Must not increase and preferably reduce risk.
- Must not require high cash and labour inputs from the smallholder.
- Must take into account the social structure and cultural norms affecting production.

In terms of tea requirements, increased or more even yields require increased water availabilty. In terms of a water balance model for a plot, this can be achieved by:

1) Increasing yield per unit of water in soil

2) Increasing the water stored in soil or

3) Increasing application of water to soil

The first two options can be achieved via management techniques and soil water conservation practices and the third via SSI technologies. Various combinations of water storage, conveyance, lifting and application were identified and ranked according to desirability. The aim of this was to identify technology combinations which would minimise labour, minimise dependence on external resources and minimise cash costs. In addition to this ease of management, reliability and the ability of the system to supply an appropriate quanitity of water were used as criteria for selection.

[67] April 28 2006.. Feradiana Tumusime. *Pers.com.*

Soil water conservation and management strategies

"Irrigation should only be considered when other more easily controllable factors such as nutrition have been corrected" (The Tea Board of Kenya, 1986)

Before considering irrigation other factors which may affect tea yields and water supply on a tea shamba can be explored. Optimal management is recommended before irrigation is explored. Ways of improving access to water for tea include:

Increasing yield per unit of transpiration

Tea within the area is currently predominantly clone 6/8 which is known to be drought intolerant. However, trials are being carried out at Byumba estate using clone 31/8 and 303/577. Early indications are that these are more drought resistant within the KGTF area. If this is the case it may be useful to establish nurseries of this variety in order to supply bushes for gap infilling. Different clone types may also have different patterns of yield distribution possibly influenced by differences in base temperature for shoot extension (Burgess, 1995). This difference may highlight clones more suitable for the high altitudes found in some areas of the KGTF area. Some smallholders had difficulty accessing bushes to fill gaps on their plots. Field officers also expressed that increased investment in nursery establishment may be useful in order to help establish or rehabilitate tea shambas. Improved clonal material could be provided for this.

Bush management practices undoubtedly affect the ability of the plant to survive climatic shocks and produce a maximum yield. Key areas of bush management include:

Pruning.This is best undertaken when soils are at their maximum soil moisture content just after the last rains before the onset of the dry season.In addition to this plucking practices can maximise tea yield and quality by being undertaken at the recommended interval of every 7 to 10 days and correct plucking practices being followed. This is understandably hard to standardise across the whole KGTF area. Cuttings from bushes should ideally be left on the shamba in order to minimise evaporation of water from the soil and in order to protect the exposed stumps.

Figure 41. Cuttings from pruned tea left on the bushes after pruning at KGTF estate in Ntungamo.

The first year of bush establishment is most critical for irrigation. Irrigation during the first year of bush establishment is likely to be useful in ensuring a plant survives a dry season when there are critical soil moisture deficits. It has been demonstrated that in moisture deficit conditions yields from tea bushes that have been irrigated in their first year are greater. Irrigation at this stage can also help in prevention of certain fungal infections.

Nutrient and pest management. Timely and correct fertilizer application can help to ensure sustained yields. Improving smallholder access to fertilizer and ensuring appropriate advice with regards to its use will maximise its efficacy. In Kenya and Tanzania, fertilizer recommendations are typically N and K_2O applied in a 2:1 ratio as this matches the rate at which nitrogen is lost. Applications at KGTF are currently 25:5:5, N, P_2O_5 and K_2O. Fertilizer is distributed according to the year's previous production with a production of 1000 kg of green leaf per hectare being allocated one 50 kg bag of fertilizer. With aforementioned ratio there is 12.5 kg of N in a 50 kg bag. A yield of 1000 kg of green leaf will remove approximately 10 kg of N from the tea bush and so nitrogen application appears to be adequate. Access to herbicide and advice on management of weeds will help to minimise water loss through competition with other plant matter **(**See Box 19 for an example of social factors affecting access to information and inputs). Access to pest control measures and dissemination of techniques for control of pests found locally such as mole rats would also serve to help affected smallholders and ensure preventative measures are available.

Box 19. Social factors affecting access to inputs
DE does not have her own smallholder number as she has a very small tea shamba of just under half an acre. Although the shamba is located next to her house and she looks after it, it is officially registered under her husband's name. As he has another wife, he focuses his attention on the shamba at the home he shares with her and consequently DE does not benefit from his official registration with the factory. Due to DE's lack of formal registration, it can be difficult for her to obtain inputs. She may obtain these from her husbands registration but sometimes she must buy these herself from the local market at what is often an inflated price as she cannot receive them directly on loan from the factory. Her informal status as a tea producer prevents her from investing further in tea production.

Use of correct equipment. Access to protectives such as gumboots and pangas for smallholders could help with implementation of the above recommendations such as correct fertilizer application.

Minimising evaporation and non-crop transpiration

Aforementioned measures such as adequate weed control and gap infilling on shambas will help to minimise water lost as evaporation from the soil and weed transpiration. As young tea is most vulnerable to invasion from weeds due to its lack of ground cover adequate weed control during this period of establishment should be emphasised. In addition to this removing trees and crops from within tea shambas aswell as those close to the edges will help to remove water competitors. However, trees are used as shade for tea pluckers and in order to protect leaf from drying out in the sun before transporting to the nearest collection centre. Therefore, their complete elimination may not be practical.

Minimising runoff and drainage

As there are signs of soil erosion on some plots in the area encouragement of SWC measures may prove useful in retaining water in the soil and redirecting run-on (Van Waesberghe, 2005). Ensuring a ground cover of at least 80% on shambas will help to minimise water lost via runoff particularly on steep slopes. Equally, run-on onto to shambas from agricultural plots or other shambas directly upslope could be managed to maximise water infiltration into the soil. This may be via directing structures such as channels and bunds or cultivation of water retention ditches such as those following a lock and spill design as currently used to some degree at both Byumba and Kigezi estates (Figure 42).

Figure 42 (Left) . Example of a lock and spill drain on the KGTF Ntungamo estate.

Figure 43 (Right). Example of tied ridging from Tanzania Ministry of Agriculture, Forestry and Wildlife (Hudson, 1987).

There has been little research conducted on SWC and tea although several measures are suggested in The Tea Growers Handbook (The Tea Board of Kenya, 1986). Recommendations include: applying mulch, utilising lock and spill drains with overflow channels, earth, stone and grass bunding. Conservation of water is particularly important on young tea plots without complete cover (Shaxson, 1971). This is also likely to be true on tea shambas with missing bushes or insufficient ground cover. Tied ridges are another recommended measure along with pitting (Figure 43). Pits are small shallow circular pits while tied ridging involves construction of a sucession of trenches linked by a soil wall. This should break before before the ridge or pit overflows (Hudson, 1992; Hudson, 1987).

As trenches are currently used on banana plantations the technology is familiar and its benefits for tea shambas may be easier to demonstrate. Mulching similar to that practiced on banana plantations along pathways between bushes may help to maintain soil structure and ensure they are not subject to erosion within the plot. Contouring and bunding are recommended in the creation of and rehabilitation of tea shambas. The use of Guatemala grass (*Tripsacum laxum*) has been undertaken in construction of bunds. Trashlines are another technology commonly used in the area which could serve as a basis for measures for tea (Briggs et al., 1998). Bunding may be particularly useful in steeply sloping areas in conjunction with drainage channels. Terraces are constructed in some steep areas although not commonly used for tea. However, step-terraces could be introduced in the establishment of new tea (Hudson, 1981). Bearing in mind the criteria modified from Underhill and Hudson, SWC activities offer a low cost, low technology option for improving yields. Considerations to be made prior to adoption of SWC measures include estimations of the labour requirement for initial construction and ongoing maintenance. Structures may be washed out each wet season and so require replacement placing additional work on smallholders. As many smallholders employ additional labour this may not be a concern. Initial investigations in the KGTF area suggest that there are potential tea yield benefits and that smallholders are receptive to the technology (Van Waesberghe, 2005). However, further investigation to ascertain the extent to which this technology is likely to benefit smallholders would be useful.

5.5 Small scale irrigation

Categorising possible irrigation systems

Taking into consideration the aforementioned criteria for possible technology selection, a decision tree was created for identification of water sources (Figure 44). A decision tool was also created with the aim of simplifying decision making with regards to possible rrigation technologies (Figure 45). In all cases the water source needs to be assessed in order to ascertain if sufficient water is available to meet crop requirements and in order to ascertain the potential impact on other uses of the source. In addition to this local skills and resources for construction and maintenance of the water source or technology must also be evaluated.

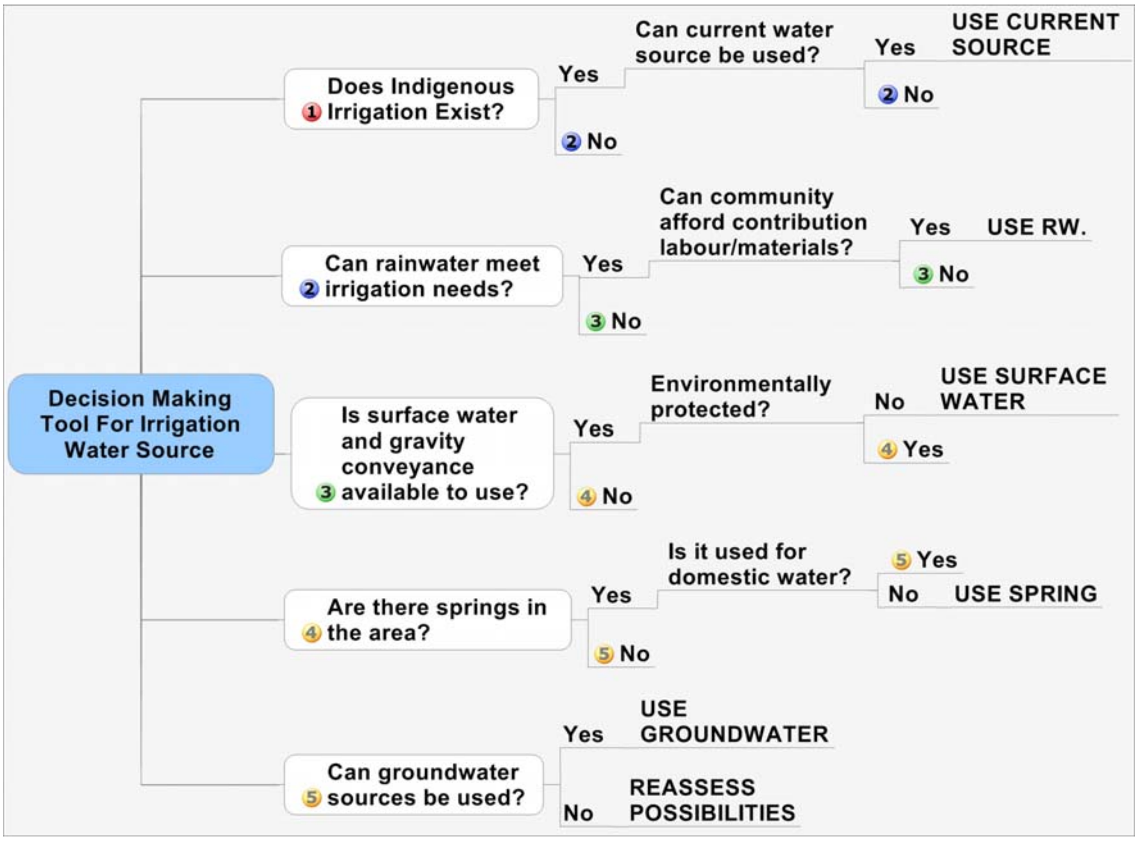

Figure 44. Decision tool for irrigation water sources.

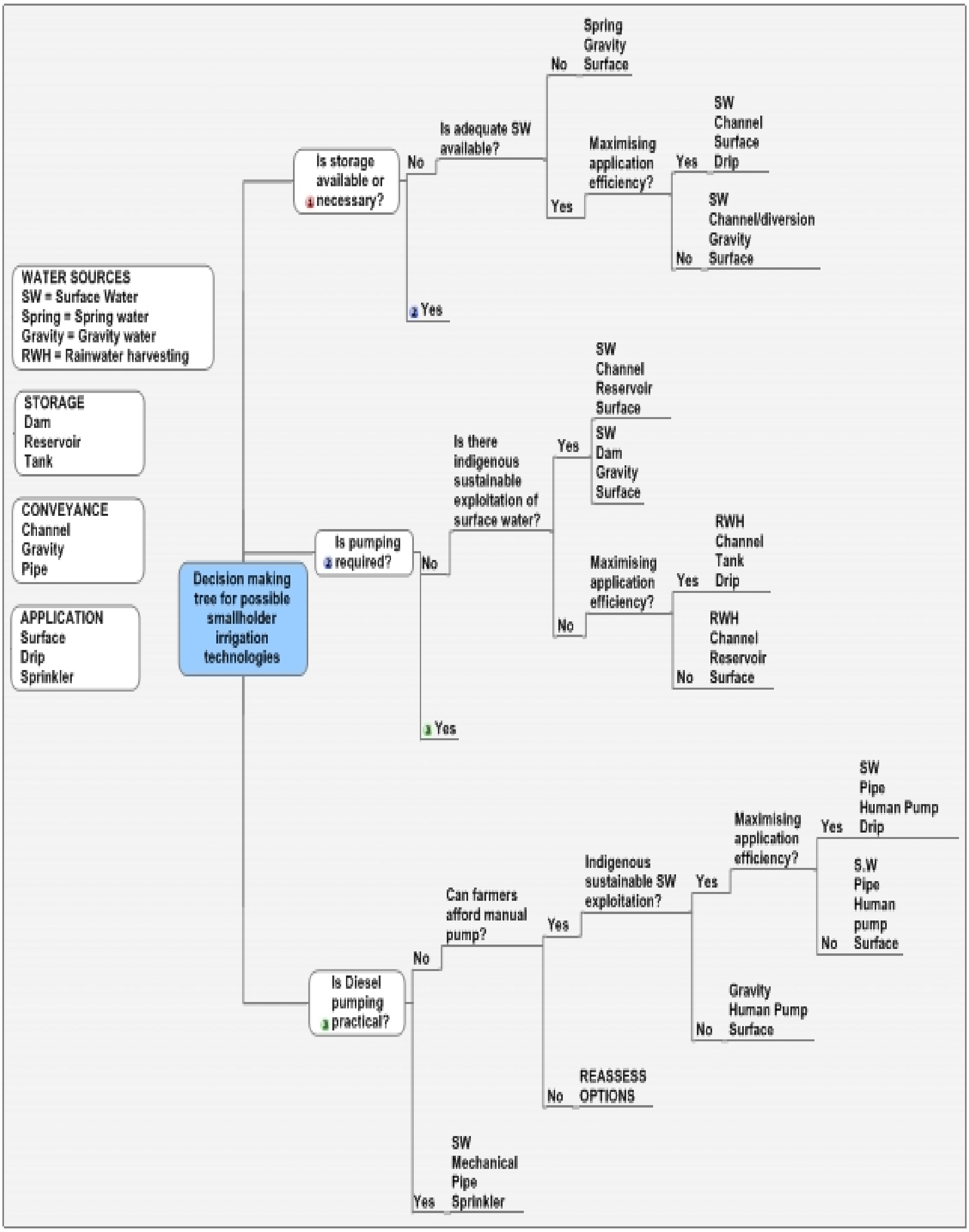

Figure 45 Decision tool for irrigation technology options.

Summary of irrigation requirements for tea and home garden crops

Mean irrigation requirements for tea are summarised in Table 13. They were calculated as described in the methodology and are summarised in appendices 10 and 11. Irrigation requirements for other crops are summarised in Table 14 (appendix 12).

Table 13. Monthly I_n requirements for tea crop (manual calculation).

Irrigation requirements for tea	
Month	Net I_n (mm)
Jan	59.4
Feb	64.6
Mar	27.6
Apr	0
May	7.9
Jun	54.9
Jul	73.2
Aug	25.4
Sep	0
Oct	0
Nov	0
Dec	17.6
Annual *In* (mm)	252
Annual *Vi* (m^3) 0.4 ha	2008
Annual *Vi* (m^3) 0.2 ha	1004

Table 14. Annual I_n requirements for other smallholder crops (CROPWAT calculations).

Irrigation requirements for other crops		
Crop	Planting date	Annual I_n mm
Sorghum & Beans	January	73.72
	March	54.34
Vegetables & Tomatoes	January & August	148.12
	March & August	122.76
Vegetables, peppers, tomatoes & groundnuts	Feb, March & August	121.44

Initial Observations

Some initial observations with regards to possible technologies and water supply can be made.

Water sources

Roof rainwater harvesting has been excluded from consideration for irrigation of tea as initial calculations indicate the quantity of water that could be obtained is not sufficient

A typical roof area is approximately: 5 x 10m = 50m^2. Monthly rainfall averages: 100mm. Therefore the volume of water caught is 50m^2 x 0.1m = 5m^3/month. However, this could provide adequate water to irrigate a vegetable plot of around 0.005 ha[68]. Therefore, it should not be excluded from consideration for home garden vegetable production. However, this translates to a 5000 l tank size if the peak water requirements for a crop are to be met. This may prove costly even if locally made tanks could be created from ferrocement. Smallholders are also likely to use this source for domestic use also and so it may make sense to combine this into the design of the system.

Application method

Sprinkler systems were excluded from consideration early on for the following reasons:

Cost. A conventional sprinkler system is costly in comparison to other application methods (Savva and Frenken, 2001).

Maintenance. There are currently no suppliers in the area who would be able to supply the replacement parts required for a sprinkler system.

Skills. A high level of training would be required in order to introduce this technology.

Pumping. A sprinkler system operating within the KGTF terrain would require a pump in order to apply water at the required pressure.

[68] Based on a net In requirement of 48 mm in the driest month for tomatoes and vegetables. 50m2 area.

However, low technology 'homemade' sprinkler systems are available. For example, the tin can sprinkler currently utilised in Kenya. This may be a viable technology for use in the area in the future.

Drip irrigation systems were also excluded early on in the study. Manual refill bucket drip kit and low head drip systems were considered unsuitable as they are unlikely to be able to supply sufficient water to irrigate tea without a high labour requirement in journeys to and from nearby water sources. Even irrigation of vegetables may require considerable labour in order to enable the required amount of water to be supplied (box 20**)**. Although micro-tube tank systems are available for customisation up to 1000l in capacity these tend to be more fixed systems and may require modification in terms of lateral spacing in order to facilitate irrigation of a tea shamba. In addition to this infrastructure for supply of parts is limited.

Box 20. Bucket drip kit

A bucket drip kit typically has a 20L volume. This equates to 0.02 m^3 water. Literature concerning bucket drip kits highlights that the bucket only needs refilling twice in a day (Practical Action, 2006). However, this is dependent on rainfall and the requirements of the crop to be irrigated. Using calculated irrigation requirements for vegetables and tomatoes, a plot of 0.0025 ha (25 m^2) might have a daily irrigation requirement of 0.008 m^3 in a dry month. This equates to 4 bucket refills. A smaller plot area would not require the same refilling. Nevertheless, as journey time to the nearest water source was cited as a concern of smallholders, the increased need for labour to collect water in for agriculture in addition to domestic use is likely to be a hindrance to uptake of this technology for irrigation of vegetables.

Moreover, smallholders may not view such a system more useful over existing and more familiar technology such as spray pumps and buckets for water application. Other drip irrigation technology such as that utilised in conjunction with pumps or roof collection tanks was also excluded due to the lack of availability of materials in the KGTF area and Uganda as a whole for creation of and maintenance of drip irrigation systems. Emitters, drip line materials and adaptors that could constitute a small-scale drip kit may be possible to import[69] and be adapted from materials available in large trading centres. However, it has been demonstrated that lack of access to spare parts for drip kit systems and knowledge of maintenance were two key factors constraining smallholder use of the technology (Kuelcho, 2003). For this reason these systems have been excluded from consideration here for tea irrigation. However, if these materials could be made available and markets for surplus guaranteed then development of this technology may be beneficial to smallholders.

Pumping

Any system which requires a mechanised pump has been excluded from consideration due to the costs involved. Approximately 30 to 50% of the running costs associated with a mechanized pump system are due to the fuel costs (Perry, 1997). Although fuel efficient diesel and kerosene pumps are available infrastructure is such in the KGTF area that even if running costs could be met fuel supply may not be reliable. However, solar powered pumps may be an option in the future as infrastructure improves. Solar panels are available in Kabale and a dealer for motorised pumps which could be powered by panels currently exists in Kampala. Nevertheless, capital costs for this technology are still likely to be higher than smallholders can afford.

What is possible?

Rainwater harvesting from a Catchment area

This technology consists of a catchment area from which rainwater is diverted to a reservoir. A technology such as this could provide water requirements for a shamba of up to 0.4ha. Earth could be used for the construction and creation of channels for conveyance and application by gravity. This makes it a low cost and low technology

[69] Kenya has a well established drip irrigation market. Organisations such as Practical Action and IDE have both introduced low cost drip irrigation systems there with some success. Therefore it is possible that these technologies will be introduced into Uganda in the future as demand for small scale irrigation increases.

option but one that would be flexible enough to be upgraded in terms of application efficiency and application method in the future. For example, lining might be used in the reservoir and a manual pump for extraction and conveyance of water. Some farmers currently engage in aquaculture which involves construction of ponds approximately 6 to 10 m by 5m and 2 or 3 m depth (60 $m^3$to 150 m^3) (box 21). This local knowledge of pond construction could be employed for reservoirs.

Box 21. Can aquaculture and irrigation be combined?
There is also the possibility that a reservoir could be combined with an acquaculture pond. However, this combination would be dependent on the location of the water source for refilling the pond and its position in relation to the tea shamba. Fish ponds in the area are usually refilled via spring or groundwater and tend to be located in valley bottoms in order to allow for cleaning of the pond and refilling to take place using nearby water sources. A smallholder plot would need to have sufficient space to enable flushing of the reservoir for cleaning. Farmers with fish ponds stated that local markets for the product were hard to find and that theft of fish was common. Costs for construction of a fish pond and fish stock were estimated to be 27 000 UGX by one farmer in the area. However labour and maintenance costs were considered to be high by many smallholders and some expressed dissappointment at the lack of markets for sale of fish.

Considerations in the adoption of a rainwater harvesting and reservoir system include:

Land availability. If gravity conveyance is to be used land would need to be available above the shamba. This is unlikely in many area as tea plots belonging to several smallholders may be grouped together. However, in areas where shambas are located close to each other a larger shared system might be a possibility.

Soil type: Sandy gravely soils such as those found in Ntungamo and within close proximity to the tea factory may be difficult to compact and may have high infiltration rates leading to losses due to drainage and low conveyance and application efficiencies. Reservoirs or channels may be lined to prevent this and the edges of the catchment area planted with guatemala and napier grass (which are already used for SWC in the area) to preserve the structure of the catchment and prevent erosion.

Reservoir storage

An earth reservoir could provide a low cost technology for collection of diverted rainwater. Creation of a reservoir model based on rainfall and ETc values for the KGTF area utilised a runoff coefficient of 0.3 in order to model possible catchment area and reservoir size. The full volume of the reservoir was set at 500 m^3. As crop requirements do not appear to exceed 40mm in a month it may be possible to design for a smaller reservoir volume. A catchment area of around $1000m^2$ could be used to fill a reservoir of $167m^2$ and 3m depth with a total of 7% empty days over a nine year period (based on rainfall 1997 – 2005). There will always be a certain number of empty or spillage days. Spillage could be redirected unto nearby crops. However, ideally the duration of empty days is not so extensive that the crop will suffer damage (appendix 13). Seepage losses in an unlined reservoir may be as great as 25 mm per day (Frasier, 1994) while there will be evaporation losses that could be as great as 4mm per day in the KGTF area. Major considerations in construction of reservoirs for water supply include:

Labour requirements: Labour is the major capital cost for construction of this type of rainwater harvesting technology (Fox et al., 2005)[70].

Irrigation losses. Lining of earth reservoirs should be considered as water losses can be a major constraint to reservoir use. This may be via use of cement, rubber tapaulin or plastic sheeting. However, investigation to determine if lining is cost effective would be necessary.

[70] Labour valuation may be classified thus as full opportunity cost – labour value is equivalent to the national wage, alternative opportunity cost - for example where labour may be costed in terms of bags of sorghum or livestock or zero opportunity cost – usually where there is high unemployment meaning labour is valued at zero Fox, P., Rockstrom, J., Barron, J., 2005. Risk analysis and economic viability of water harvesting for supplemental irrigation in semi-arid Burkina Faso and Kenya. Agricultural Systems 83, 231 - 250..

Figure 46. Tea shamba located above a fish pond in Rutenga

Spring source and gravity conveyance

Kanungu district has many springs and small rivers and is likely to possess many which are currently unexploited. A typical spring in nearby Kabale district may possess a flow rate of 0.2 l/sec[71]. With storage over 24 hours this could provide 17280l or 17 m^3. This is enough water to irrigate 0.6 ha of tea. Gravity pipes or surface channels could then be used to convey water to the shamba. Considerations in the potential for adoption of this technology include:

Water rights. Resources such as springs tend to be exploited for the benefit of more than one household. This resource would need to be developed communally in consultation with surrounding households (see box 22 for an example of communal

[71] November 2006. James Webster. *Pers.com.*

water priorities). If it is to be used for tea irrigation this may involve consultation with smallholders who are not tea producers.

Communal management of the resource for irrigation would require establishment of irrigation scheduling and creation of rules and rights governing use of the irrigation system to ensure that access to the water is fair and equitable. There is a great deal of literature concerning communal rights and rules concerning irrigation and a full feasibility study of the potential for exploitation of this resource should consider these issues.

Box 22. Smallholder prioritisation of water use

Hand dug well in Murenge used for domestic water collection.

In Murenge near Rwambogo in the KGTF area six local families use a hand dug well (approximately 1m x 0.5m) for domestic water collection. Although a protected spring is located a 30 minute walk away Murenge is located on a steep incline and carrying water back up to the settlement is awkward. In addition to this the protected spring was created by a more wealthy land owner who does not live in the settlement and some smallholders feel it is "his water" and not theirs. This hand dug well may indicate the presence of a spring nearby and could be investigated further in order to ascertain it's rate of flow. Some smallholders expressed a desire to improve this water source as *"the water is not good. The cows go to drink water from that well and leaves fall in the water "* but were unsure how to start. It may be possible to irrigate a nearby tea shamba with this water using a manual pump. However, at present domestic water supply is a greater priority for the community. It is increasingly recognised that smallholders do not make the same distinctions between domestic and agricultural water use that engineers have made in the past. Therefore, any irrigation system is likely to serve other water use functions.

Manual pumps and surface irrigation

Manual pumps for small scale irrigation are currently popular SSI technologies and becoming more widely available in East Africa. Although a variety of lift heights are recorded for manual pumps within advertising literature[72], suction lift up from a water source is typically not greater than 7 m in the field[73] (IPTRID, 2000; Carter, 2006). Water application to a height above this is dependent on design of pump. However, as height increases discharge will decrease. Therefore, plots located at heights above 7 m are unlikely to benefit from manual pumping. A suitable manual pump for exploitation of water sources in the KGTF area might be the treadle pump. These can be used to exploit surface water sources such as wetlands, rivers, ponds, dams or open wells.

This could be used in conjunction with surface irrigation methods. Treadle pumps are foot operated low head pressure or suction pumps specially designed for SSI. Foot operation makes use easier and uses less energy than hand operated pumps (Fraenkel, 1986). Water application rate can be up to 2.5 to 5 m^3 per hour (IPTRID, 2000). However, application rates in the field are commonly lower than this. Within Uganda the supermoneymaker pump is currently available as an import from Kenya. This is a pressure and suction pump able to irrigate areas ranging from 0.3 to 0.8 ha over a period of 8 hours continuous use (Kickstart International, 2006). Lawrence & Hyman compared motorized pumping, bucket lifting and use of a treadle pump for irrigation in Senegal and found that over a six year period the treadle pump offered the greatest financial benefit for smallholders (Hyman and Lawrence, 2001). Specific considerations for introduction of this method of irrigation include:

Environmental impact. An environmental impact assessment before use of surface water sources such as wetlands for irrigation may be required especially considering current legislation in Uganda concerning wetland use.

[72] For alternative lift height of 14m see Kickstart International, 2006. Kickstart moneymaker pump. Kickstart.
[73] 2006. Richard Carter. Pers. Comm. Re: Lift height of treadle pumps.

Social impact. A social impact assessment of possible effects on livelihood assets including income, labour, education and gender would be useful in ascertaining benefits and possible drawbacks of the technology. In addition to this more extensive use of wetlands may hinder access to other materials smallholders are reliant on such as grasses for thatching and basket construction.

Maintenance. This is a significant concern as there are currently no irrigation engineers in the area. Although the factory has engineers who frequently help with mechanical problems at other institutions additonal support would be required. Reliance on imported technology from Kenya is not ideal without adequate mechanical support available locally.

Costs. The cost of the pump is likely to be in the region of \$50 - \$120 (Kickstart International, 2006). Therefore introduction of this would need to be via an appropriate credit scheme to enable farmers to invest and pay back loans for such a technology.

Labour. Labour requirements may be high for this technology especially during dry seasons when irrigation scheduling may mean the plot must be irrigated daily.

Assuming that 1 m^3 of water can be applied each hour it would take approximately 6 hours to irrigate 0.2 ha of tea with a daily water requirement of 6 m^3. This is a promising technology to pilot for irrigation of tea on plots lower than the water source or used on plots with even terrain at heights not greater than 7m from a viable water source. This technology would also be appropriate for smallholders who wish to irrigate vegetables.

River or stream diversion

River or stream diversion can be seen as an extension of current wetland and stream exploitation techniques. The advantage of utilising streams and rivers for irrigation is that smallholders are already familiar with the technology and construction and maintenance skills required. Further investigation of the feasibility of this irrigation technology may enable elicitation further information of the constraints of this system and farmers own suggestions of improvements that they would like to make. Viewing river and stream diversion as an extension of the current irrigation system is likely to be beneficial. Figure 47 shows the position of a stream and channels channeling water to irrigate cabbages and potatoes cultivated on raised bunds. Figure 48 shows a perennial stream in Mafuga which currently runs onto a road. Water could be diverted from a

Figure 47. River irrigation in Rutenga. Blue line shows position and direction of flow of river.

Figure 48. Perennial stream in Mafuga.

source such as this if additional measures are taken to strengthen the soil structures and banks supporting the stream flow to avoid erosion. It may be possible to create micro or macro[74] catchment structures and small dams from streams such as this to divert water onto cultivated land. This may also help to minimise damage caused to roads and pathways by overflowing streams during the wet season.

[74] Micro-catchments are those where the catchment area lies adjacent to the irrigable land while macro-catchments are those located above the irrigable land Prinz, D., Tauer, W., 1994. Application of remote sensing and geographic information systems for determining potential sites for water harvesting. In: Water harvesting for improved agricultural production. FAO, Rome..

Watering cans & spray pumps

Knapsack spray pumps and watering cans are all currently used by farmers to apply water to crops. However, access to them is limited and they are not easy to acquire locally. Several smallholders expressed a desire to have the option of purchasing spray pumps locally or having greater access to them. These could be utilised for irrigating small vegetable gardens or young tea during its establishment.

Household individuality and smallholder irrigation priorities

Smallholder irrigation priorities currently focus on high value seasonal crops (tomatoes, cabbages, potatoes and occasionally rice) that can also be used to supply home food requirements (box 23). These tend to be grown over a small area and so manual irrigation is occasionally undertaken when a water source is located close to the plot. Smallholder concerns about food security, in conjunction with the high income that can be obtained for these crops for a relatively small investment make these popular irrigation choices. *"I would love to grow tomatoes as they fetch a high price but they need water"*[75] (Box 23).

Box 23. Irrigation to support home food consumption

DE works hard to ensure that her family consisting of her unmarried daughter, son, daughter-in-law and granddaughter has sufficient food. However, she often feels frustrated that she has little control over her environment and eagerly seeks the tools necessary to improve her situation *"I'd like to end my poverty. I find I can't help myself. When I need salt I can't even buy it".*

Although, DE is reliant on tea as her main source of income she would prefer additonal field officer support and advice in this area. Given a choice DE would like to increase her bean yield or grow additional food for the household as she finds that she must often purchase extra to provide enough for her family. DE grows sorghum and beans on a ¼ acre plot that she owns. It would be possible to irrigate this using local spring water sources. However, the location of her plot would make this an expensive and high technology option (appendix 9)

In order to grow additonal food for the family rainwater collection might present a viable option in order to supply a vegetable garden surrounding her home. Land is limited here. However, collection in a tank from the roof would enable the water to be sprinkled onto a plot or used for cooking saving her the 20 to 40 minute journey to collect from the nearby protected spring sources.

[75] June 26 2006. CG Itembezo. *Pers.com.*

Although tea is a significant source of income it is a crop which is robust enough to survive the dry season. This quality makes it an ideal insurance crop for farmers who may focus on other enterprises for their main source of income. Management of a tea shamba requires labour and regular investment in order to obtain optimal yields. However, not all smallholders have available resources or are willing to risk the majority of their investment on a tea shamba. This is particularly the case for smallholders who cultivate on the smallest shambas as they may also have limited access to other land. This is demonstrated in diagrams of smallholder plots and homesteads which highlight logistical difficulties such as conveyance of water and irrigation of fragmented land (appendix 9). It may be that the smaller the plot and total land owned by the smallholder the greater the risk by reliance on only one cash crop. In addition to this smallholders may have other water use priorities for domestic or productive use (box 24).

Box 24. Multiple water use

"When communities design their own water systems,they invariably plan for multiple uses"(IWMI, 2006)

Increasing attention is being given to multiple use water systems at both a policy and research level. Distinctions between productive and domestic water use have dominated water systems design in part due to a demarcation in engineering disciplines. However, there is now considerable research demonstrating the way in which users may adapt single use systems for multiple use in order to meet their needs (Laamrani et al., 2000; Van der Hoek et al., 1990). It is now recognised that making provision for domestic use within irrigation systems and vice-versa can have positive effects on livelihoods enabling users greater flexibility and improving the long-term sustainability of a system (IWMI, 2006).

5.6 Recommendations

This research has opened up several strands of enquiry that could be pursued further.

Analysis

Further finer grained analysis of yield data would enable identification of specific geographical areas where yield evenness and kg/ha^{-1} vary which could then be correlated with soil and geological maps in order to create a KGTF specific map. This would enable the factory to plan area specific interventions to support infrastructure and leaf production and target leaf increase initiatives to appropriate collection centres. Creation of a live database with this information would be useful in order to monitor changes in leaf obtained according to collection centre in real time. Investigation of the relationship between collection centre and leaf quality would also be useful as an additonal layer to yield analysis.

Further investigation of climate data may reveal reasons for the apparent idiosyncracies in different climate centre recordings and enable yield data to be more accurately modelled in relation to climate. Modelling of SMD could include greater analysis of the relationship between yield and SMD. This could also be undertaken across the KGTF area in order to ascertain the relationship between yield, rainfall, altitude and SMD. It may then be possible to create a prediction model estimating future yields based on climate and yield patterns.

Field Investigations

Greater understanding of factors affecting smallholder livelihood sustainability would be useful in identifying factors affecting smallholder commitment and investment in tea production. Specific areas for future study include investigation of labour and tea production including time invested in tea production and sources of labour for tea production. A full farming sytems analysis in areas such as Rutenga, Ntungamo and Buhoma would enable identification of and comparison of the site specific factors affecting how farmers prioritise their activities and management input for each crop.

A full dry season impact analysis classifying dry spells in the climate record according to severity would be useful in conjunction with analysis of the current income loss sustained due to lack of tea income in dry spells. This could be conducted in contrasting geographical areas and with different shamba sizes enabling a full cost-benefit analsyis to determine potential income increase of any irrigation system.

It would be useful to investigate understanding of and use of current water sources and technologies in the area. This study has highlighted local policy and governmental factors influencing management of water at a domestic level. The extent to which this may impact upon irrigation uptake and sustainability in the future would enable further planning and feasibility of technology choices to be more targeted. In additon to this the relationship between smallholders and structures such as KGTF, local government and local organisations would help to elucidate the factors that influence their access to information and services.

Pilot Interventions

As this study was unable to investigate potential technologies in any great depth it would be useful for pilot trials and full feasibility studies of technological options to be undertaken.

Soil water conservation (SWC)

SWC measures could be piloted on specific farms in order to ascertain how receptive smallholders are to the technology and how useful it is. Maintaining records of yields at a selected study site may help in identifying efficacy of the measure. SWC measures may be particularly suited to the Ntungamo area in the vicinity of the tea factory as the soil is of a sandy loam type and so may benefit from measures to improve water retention in the soil.

Rainwater harvesting (RWH)

RWH in the form of catchment area collection and diversion to a reservoir is hindered by land availability. However, there are farmers such as BC who may be appropriate for piloting of this technology as land is available above the tea shamba.

River diversion

This could be piloted on a small scale in the Rutenga, Mafuga and Itembezo areas where there are several small streams and gulleys that have both perennial and seasonal water supplies. Diversion may be possible onto plots in these areas.

Treadle pump

Treadle pump exploitation of surface water sources could be undertaken for both tea and small vegetable plot irrigation. Areas where this could be in explored might be Buhoma through which the river Munyaga flows. This has tributaries which may also provide sufficient water to pump. Tributaries of the river Ishasha may also provide areas with suitable plots and river access to exploit this source.

5.7 Conclusions

This study has presented a broad overview of the KGTF physical and social environment with a view to identifying areas for future investigation. Elements of the physical environment that impact upon water management and tea production have been presented. The relationship between the varying components of smallholder livelihoods has been mapped in relation to tea production and water management strategies. Potential constraints and areas for consideration have been outlined and a range of technologies presented for further consideration.

The approach taken in this study was necessarily broad in scope in order to allow for investigation of the relationship between tea production, physical environment and social context. Literature study revealed the environmental requirements of tea and the paucity of literature concerning tea production in Uganda. A water balance framework was identified for conceptualising water use on a tea shamba. Water management was presented in light of this framework with SWC measures considered and the main components for consideration in a potential irrigation system identified. An overview of current critique of approaches to water management and irrigation intervention was presented alongside the sustainable livelihoods framework for investigation of the factors impacting upon smallholder livelihoods and water use and their potential positive or negative impacts upon smallholder vulnerability.

Yield data revealed annual and seasonal fluctuations in green leaf received by KGTF. Annual and seasonal rainfall patterns were shown to correspond to this pattern of yield received while soil moisture deficit modelling attempted to present a finer analysis of this in light of different soil types present within the KGTF area. Eveness of yield was used as an initial starting point for identification of differences between different geographical areas. Eveness was shown to be potentially related to differences in soil type and correspondingly the number of water stress days. Annual yield amount was shown to vary considerably from site to site and may reflect altitudinal differences in the KGTF area. None of these were investigated for statistical significance. However, when yield eveness was investigated at an individual level a wide variation was discovered within smallholder yield patterns at any given collection centre. These are likely to be the result of socio-economic factors which impact upon tea production.

Water management for tea has been considered in terms of utilising existing *in situ* water such as rainfall and soil water. A variety of management and infrastructural options have been presented in order to maximise use of *in situ* water and in order to maximise yield obtained from water available. Water application technologies are presented for use in the KGTF area. Irrigation of tea at a smallholder level is limited due to the terrain and lack of supporting infrastructure for irrigation technologies which may be difficult to maintain without appropriate knowledge and skills.

A reduction in smallholder vulnerability may occur via support for technological intervention which allows for a more even distribution of tea yield thus reducing the pressure of seasonal labour requirements which currently are such that smallholders cannot afford or source sufficient labour to harvest all the leaf on their shamba. Many smallholders invest limited time in tea as they have other enterprises. Moreover, increased dry season yields may not generate more income for smallholders as annual total tea yield may not increase significantly. Potential yield increases from any intervention should be modelled in order to ascertain the extent of irrigation benefit. In order to generate real benefits for smallholder livelihoods, other strategies may be required in order to support development of access to goods and services and support for social organisations. As smallholder irrigation priorities appear to rest with cash and food crop production any irrigation system must account for the likelihood that smallholders will utilise the system for production of other crops. In addition to this the demand for closer domestic water sources and livestock water needs suggest that any irrigation system is likely to be used for domestic and other productive uses.

Long-term support of existing smallholder organisations that engenders farmer led requests for support and enables greater links between smallholder groups and external agencies may help contribute to a sustainable introduction of technological solutions to the area. Farmer groups are only likely to be sustainable if they address issues of major concern to their members and while technology may be one of these, supporting organisations need to be flexible enough to recognise other possibilities (Tripp, 2006). Technological intervention does not exist in a social or environmental vacum and so the presence of appropriate structures to support its development is imperative. A paced and considered development of relevant technologies can only occur with a long-term commitment from an organisation that allows for creation of and support of relevant infrastructure and the changing social environment.

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Appendix 1. Diagnosis & Design (D&D) Sample Questions

Adapted from Raintree J.B, 1987

Land

Land Use

History

How long has the smallholder been farming this particular land?

What form of land use was practiced at the beginning of the period?

What changes in land use have occurred and why?

What was the condition of the land at the beginning of this period and what changes have occurred in the meantime? (note: vegetation, soil etc.)

Farm Resources

Land

Estimate appoximate area of land.

Estimate appoximate area of land for tea.

What is the land used for? (crops, grazing, fuelwood).

Does the household have access to other land outside the farm? If so note location, use (crops, grazing, fuelwood etc). Approximate area and terms of usage (e.g communal, private, borrowed, rented etc.)

Tea

How many shambas does the smallholder and the family own?

Where are they located?

What size are they?

What is the history of the tea shamba? Who owns it now and who used to own it and for how long?

What is the management practice for the tea shamba?

Plucking regime?

Pruning regime?

Inputs?

Other management activities?

Kg per month from tea in dry and wet seasons?

Income from tea?

Problems with tea production?

What constraints to production are there?

Livestock

What livestock does the farm have? Note type of animal and its use.

Labour

How many people work on the farm “full-time”? Part-time?

What are the ages and sex of the workers?

Does the farm hire labour? For what tasks? For how long?

What is the source of cash for this and how much is paid?

Water

What water sources does the farm and household have? E.g gravity, stream, pump, collecting tank etc.

What are the water sources used for?

At what distance are water sources located?

How long does it take to collect water for the household?

Who collects water for the household and how many times in a day?

Is the water source available in the dry season?

What problems if any do you have with water supply?

Cash Subsystem

What are the main cash expenditures of the household? Questions directed to all adults present. Aim is initial free response then elicitation “what else?”. Areas to cover: staple foods, minor foods & sundries, fuelwood, building materials, crop inputs, hired labour, farm equiptment, livestock, veterinary services, raw materials for home industry, school fees, social expenses.

What are the sources of income for the household? Elicit then probe for off-farm employment, gifts or remittances, sale of cash crops, “surplus” food crops, livestock or livestock products, trade or exchange of goods e.g milk, manure, wool etc, cottage industry products e.g basket and mat weaving, other sources. Rank main cash sources.

Does the household always have enough cash to meet its needs? If not which expenditures are most difficult to meet?

What does the household do if it cannot meet cash expenses?

Savings & Investment

Does the farm have a savings or investment enterprise to help meet extraordinary expenses e.g higher education fees, a new house etc? If not why not? Note savings and investments may include livestock or woodlots which can be cashed in at a later date representing a form of savings.

Trouble-shoot existing savings/investment enterprises to identify constraints, causal factors and potentials for improvement.

Food Production Subsystem

Which of the following best characterises the general strategy of the household with respect to food supply? (not direct question but around topic to ascertain).

a. The household aims to produce nearly all of its staple foods and usually succeeds in doijng so.

b. The household would like to produce nearly all of its staple foods but often fails to do so.

c. The household aims primarily to generate sufficient cash income to purchase a substantial amount of its staple foods and relies on farm produced food only to supplement purchases.

If food shortages are experienced then how regularly? Elicit.

a. Only bad years.

b. Most years.

c. Even good years.

Which foods are affected?

Appendix 2. Socio-economic feasibility

Adapted from (Underhill, 1990)

Aspects of the socio-economic system for consideration in assessing the feasibility of a technical intervention:

1. Sexual divison of labour tasks and responsibilities of the farm family. In what periods of the year are peak labour requirements?

2. What is the predominant farm family composition?

3. How would any project intervention affect the household structure including labour supply and women and children?

5. How does childrens education affect labour supply?

6. What do people eat and how adequate is their diet?

7. How is the farming system affected by weather, conflict, unreliable supply of inputs etc. What recent, past and future changes are expected?

8. Would project intervention increase production risks for some people?

9. How far are basic needs of smallholders being met?

10. What impact would project intervention have on these needs?

11. What is the average level of income of the people at present and how is this distributed between and within households?

12. What change in income levels can be expecte from the project and how would theses changes be distributed? Would some smallholders be worse off?

13. Is the proposed intervention necessary? Would water be better used elsewhere? Are there possible developments for this community which should receive priority over irrigation or which can be integrated with it, e.g improved domestic water supply?

14. How would the proposed scheme affect the social structure: (a) the power base of the community. (b) the poor and landless?

Skills

1. What is the present level of skill relevant to potential technologies?

2. Farming skills, agricultural practices and tools.

3. Mechanization, experience with machinery, animal power.

4. Adaptability to new methods, machines and tools.

5. Managerial skills, actual and potential – communal or individualistic traditions and skills; role of private enterprise; entrepreneurship; literacy; accountancy.

6. Existing groupings that might become the basis of irrigation organizations.

Motivation

Does the target group really want the scheme? What degree of self-help is possible/probable?

Have the local people carried out self-help projects before? If so how, and with what results? What lessons can be learnt?

Appendix 3. Rainfall comparison

Rainfall was compared where available for corresponding dates between KGTF and Ruhija, Rushambya and Buhoma. Readings for daily rainfall were plotted on scatter graphs in order to determine if a good correlation between sites existed. Regression statistics and a one way analysis of variance (ANOVA) were calculated using Excel. Monthly data was divided by the number of readings available and these averaged out daily figures were plotted against each other to determine if a better correlation could be found. Regression analysis was then performed on this averaged out data also. The intercept line was set at zero for all statistical analysis

Buhoma

Summary output of regression statistics comparing Buhoma and KGTF rainfall with line fit through zero. The adjusted R2 value is 0.8

Regression Statistics								
Multiple R	0.923101971							
R Square	0.852117249							
Adjusted R Square	0.83822836							
Standard Error	72.8839388							
Observations	73							
ANOVA								
	Df	***SS***	***MS***	***F***	***Significance F***			
Regression	1	2203830	2203830	414.8722	2.27097E-31			
Residual	72	382468.9	5312.069					
Total	73	2586298						
	Coefficients	***Standard Error***	***t Stat***	***P-value***	***Lower 95%***	***Upper 95%***	***Lower 95.0%***	***Upper 95.0%***
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
KAYONZA	1.188058101	0.058328	20.36841	1.33E-31	1.071782441	1.304334	1.071782	1.30433376

Summary statistics comparing Buhoma and KGTF with zero readings ommitted and line fit through zero.

Regression Statistics								
Multiple R	0.917732							
R Square	0.842233							
Adjusted R Square	0.813661							
Standard Error	2.493617							
Observations	36							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	1161.831	1161.831	186.8458	2.25E-15			
Residual	35	217.6345	6.218128					

Total	36	1379.465						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
1.593548387	1.180147	0.086337	13.66915	1.34E-15	1.004874	1.355419	1.004874	1.355419

Ruhija

Summary output of regression statistics comparing Ruhija and Kayonza rainfall with line fit through zero.

Regression Statistics								
Multiple R	0.2483748							
R Square	0.061690041							
Adjusted R Square	0.061331233							
Standard Error	8.624732457							
Observations	2788							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	13630.03	13630.03	183.2338	1.77E-40			
Residual	2787	207313.8	74.38601					
Total	2788	220943.8						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
KGTF	0.241261715	0.017823	13.53639	1.76E-40	0.206314	0.27621	0.206314	0.27621

Summary of regression statistics output with zero readings ommitted and line fit through zero.

Regression Statistics								
Multiple R	0.806392							
R Square	0.650268							
Adjusted R Square	0.638774							
Standard Error	2.406392							
Observations	88							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	1	936.7183	936.7183	161.7619	1.83E-21			
Residual	87	503.793	5.790724					
Total	88	1440.511						

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
1.487097	0.717897	0.056445	12.71856	1.49E-21	0.605707	0.830087	0.605707	0.830087

Rushambya

Summary output of regression statistics comparing Ruhija and Kayonza rainfall with line fit through zero.

Regression Statistics								
Multiple R	0.302597							
R Square	0.091565							
Adjusted R Square	0.091193							
Standard Error	9.669635							
Observations	2686							
ANOVA								
	df	***SS***	***MS***	***F***	***Significance F***			
Regression	1	25304.7	25304.7	270.6332	5.19E-58			
Residual	2685	251052.4	93.50184					
Total	2686	276357.1						
	Coefficients	***Standard Error***	***t Stat***	***P-value***	***Lower 95%***	***Upper 95%***	***Lower 95.0%***	***Upper 95.0%***
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
KAYONZA	0.334636	0.020341	16.45093	5.18E-58	0.294749	0.374522	0.294749	0.374522

Appendix 4. Market Prices

	April	May	June	July
Dry beans	1000UGX/Kg	600 UGX/Kg	7 – 800 UGX/Kg	800 – 900 UGX/Kg
Groundnuts		2000 UGX/Kg	1500 UGX/Kg	1500 UGX/Kg
Millet	300 UGX/Kg	250 UGX/Kg	250 UGX/Kg	
Tomatoes		100, 200, 500 UGX/Portion depending on size of each fruit. Portion approx. 5 – 10 fruits.	100, 200, 500 UGX/Portion depending on size of each fruit. Portion approx. 5 – 10 fruits.	
Rice	700 UGX/Kg	1000 UGX/Kg	1500 UGX	
Cassava	1000 UGX/ Endebbe	1000 UGX/Endebbe	1000 UGX/Endebbe	
Sweet potatoes	6000 UGX/Endebbe	6000 UGX/Endebbe	6000 UGX/Endebbe	6000 UGX/Endebbe
Irish potatoes	6000 UGX/Large Endebbe	6000 UGX/ Large Endebbe	6000 UGX/Large Endebbe	
Matooke	500 UGX/Hand 2000 UGX/Branch		500 UGX/Hand 2000UGX/Branch	500 UGX/Hand 1500 – 2000 UGX/Branch
Peppers	200 UGX/4			
Tobacco	1000 UGX/Roll	1000 UGX/Roll		

Appendix 5. AB budget

EXPENSE	COST UGX/Year	DETAILS
Labour	150 000	
School Fees	108 000	36 000/term x 3 = 108 000UGX
Medical Care	40 000	40 000UGX/ 4 day visit
Clothing	100 000	
Food Extras		10 000UGX/week = including: meat, salt, sugar, rice, milk
Tea		
Fertilizer		84 000. As loan from factory. Deducted from green leaf pay slip. 2 debts so 60UGX/kg deducted
Herbicide	20 000	10 000UGX/year (Tea) 12 000UGX/year (Coffee)
Land Buying	Occasional	200 000/plot or 300 000/acre – buy once every 2 or 3 years
Savings with Nikundire Group	132 000	10 000/month = 120 000 + 1000/month emergency
Transport	24 000	2000/month
Total	574000	

INCOME SOURCE	INCOME UGX/year	DETAILS
Rented Shamba	20 000	60 000/year = 20 000/this year so far. Rents out tea shamba to another farmer (4 months of this year..
Tea	120 000	Dry month = 100kg Wet month = 250kg Based on 160UGX/kg 1650kg/year = 264 000 UGX/year.. Subtract 60UGX/kg for loans from factory = 144 000UGX loan repayments.
Land Clearing	120 000	10 000/month
Coffee	120 000	800- 1500UGX/kg. Average 50kg/season. So 40 000UGX or 75000UGX (2 seasons/year)
Goat Kid	150 000	25 000 – 40 000UGX/goat. Used when unexpected expenses occur. 3 x 40 000 & 1 x 30 000. 2-3/year.
Total	540 000	

Appendix 6. BC budget

EXPENSE	COST UGX/Year	DETAILS
Thatching	100 000	Thatching goat, rabbit, pig & part of the house.
Livestock Veterinary Treatment	840 000	Includes Transport, salary & medicine. Can be more than this.
Grazing Costs	300 000	
2 Workers	600 000	Housing,food etc.
Manure collection	312 000	Tarpaulin for manure collection. 6000UGX/week = 312 000/year
Tea pluckers	367500 (52 500/month)	70UGX/kg 4 – 5 people employed Usually pluck 50kg/person/day Employed for 7 months of year during rainy seasons. 3 plucking days/month
Herbicide	20 000	2 x 10 000
Fertilizer		80 000 2 x 40 000 (Deducted from GL payments)
Market Tax	12 000	2000 each trip to market (6/year)
School Fees	774 000	2 x 87 000/term = 174 000 UGX/Year. 3 terms in year. 1 x 600 000 (Sister's living expenses, Kabale)
Uniforms	48 000	12 000 x 4
Health	250 000	
Water	400 000	2000UGX/day. If raining collects from roof (approx. 200 dry days).
Total	4 023 500	

INCOME SOURCE	INCOME UGX	DETAILS
Goat	1 750 000	Sells when need for school fees – can sell 70 in a year = 1 750 000.
Matooke	600 000	50 000/month if well maintained
Tea	154 990	40 000UGX/month rainy season (500kg). 10 000UGX/month dry season

		(62kg). Translates as 280 000UGX/Rainy (3500kg). 50 000UGX/Dry (312kg). = 3182kg– = (55UGX/kg deductions = 175 010 deductions) 330 000 – 175 010 = 154 990
Rice	600 000	300 000/ season x 2
Coffee	300 000	150 000/ season x 2
Cassava	50 000	
Construction labour	150 000	Skilled in making goat & pig sheds. Not commissioned to do this every year.
Pig Breeding	300 000	15 000/mating opportunity. Approx. 20 per year.
Total	3 904 990	

Appendix 7. CG budget

EXPENSE	COST UGX/Year	DETAILS
Education	230 800	Senior - 35 000 UGX/term = 105 000/child x(2 children) Primary - 3000 UGX/term = 9000 + 1000 Security (School protector) + 400 (Teaching) = 10400/child x (2 children)
Uniform	28 000	7000 UGX x 4 children
Books	43 000	4000 UGX/term x 4 children
Clothes	168 000	Home:1 x year 30 000/child /year = 120 000/4 children Sunday:12 000/child/year = 48 000
Sunday clothes (CG)	35 000	35 000/year
Clothes for husband – buy in Itembezo or Kanungu	40 000	40 000/year (trousers, shirt,coat)
Transport	180 000	15 000/month.
Medical care	80 000	80 000/year (incl. transport – stay for 1 week @ 40 000, + food x 2)
Milk	146 000	400UGX/L/Day
Sugar	41 600	1600/kg every 2 weeks
Salt	10 400	200/week
Rice	218 400	1400/1kg. 3kg/week = 4200/week
Tomatoes	31 200	600/week. (3/200UGX)
Meat	36 000	3000/month. 2kg goat. Occasionally 2500/cow meat.
Fertilizer		40 000 x 2/year (deducted from income)
Herbicide	10 000	10 000/year.
Plucking labour	31 500	70UGX/kg. Mar, Apr & May (pluck 20 – 40kg). = 13 weeks/2. 4 people every 2 weeks during the rainy season.
Pruning		4000 x 5
Rent	30 000	15000UGX/garden.

Land clearing	30 000	2 plots cleared/year. 1 acre/ 15000 = 30 000total
Savings Club	24 000	2000/month.
Bride price		From last year. 6 goats, 2 cows. 150 000 still to pay. Money will come from tea, coffee & husbands work as logger in Kampala.
TOTAL	1 413 900	

INCOME SOURCE	INCOME UGX	DETAILS
Livestock	160 000	4000/chicken (5 months) = 20 000 20 000/goat (2/year) = 40 000 80 000 – 100 000/calf
Tea	135 960	1236kg/year = 197 760). 50 UGX deduction/kg.= 61 800 deduction for fertilizer repayment.
Matooke	75000	30 x 2500/bunch
Coffee	30 000	3000/endebbe. 10 per year. (unprocessed)
Maize	50 000	Sack sold to school
Sugar Cane	20 000	Not available yet
Banana Brew	24000	1 jerry can = 4000 x 6 months
TOTAL	469 960	

There is a huge discrepancy between income and expenditure. CG acknowledges that the family lives with extensive debts and manages this by debt restructuring from one source to another. However, even accounting for this there is likely to be a miscalculation in estimated income and expenditure.

Appendix 8. DE budget

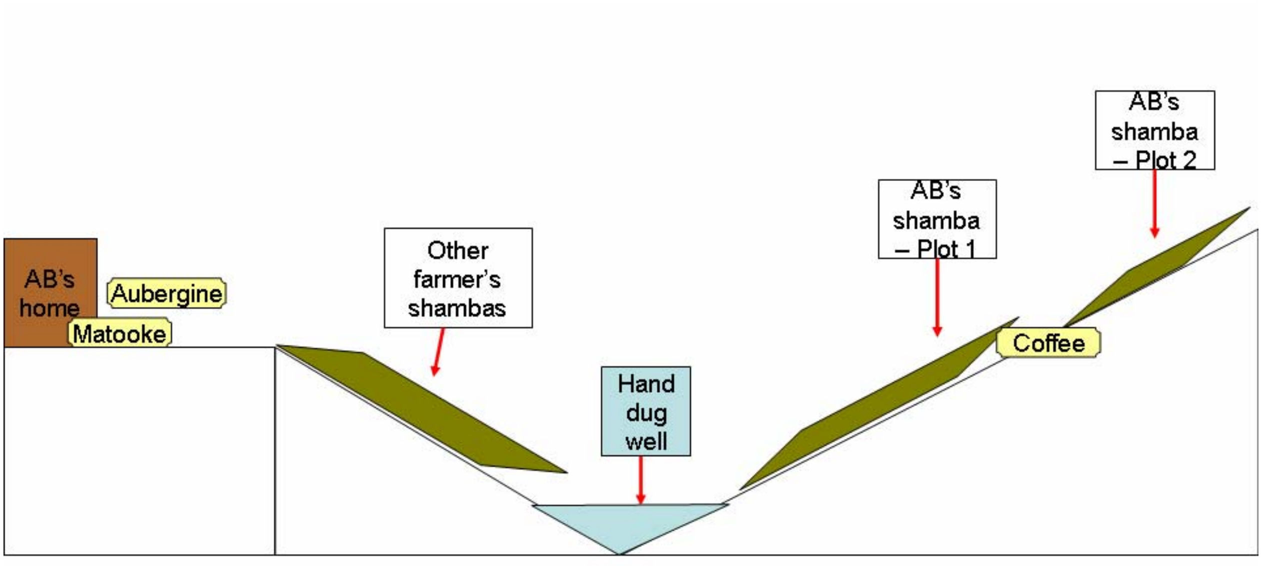
EXPENSE	COST UGX/YEAR	DETAILS
FOOD EXPENSES (3 Months of year)		
Posho (Maize flour)	36 000	Posho @ 3000UGX/Week = 12 weeks.. 800UGX/1 Kg
Beans	14 400	1800UGX/basket. Uses 2 baskets (3600UGX)/3 weeks.
Irish Potatoes	36 000	1500UGX/basket. 3000UGX/Week
Matooke	6000	2000UGX/bunch. 1 per month
Rice	7500	1500UGX/kg. 1 or 2 kg/month.Based on 5kg/3months.
Millet	2000	
Chicken	17 000	Cock – 5000UGX Chicken – 3500UGX 4 per year. Based on 2 chickens 2 cocks.
Christmas Goat	17 500	2 families share one. Each family pays 17500UGX.
Christmas Posho	40 000	50kg bought = 800UGX x 50 = 40 000UGX
Medical Care	70 000	Can be up to 100 000UGX/year
TEA		
Spray Pump Hire	5 000	Once a year
Herbicide	15 000	
Fertilizer		40 000
LABOUR		
Cutting & clearing (Every 6 years. Shambas alternated)	20 000	5000UGX/person/day contract – upper tea shamba 1500UGX/person/day contract – lower shamba.
Land Preparation (Every year)	5400	1500/day cut & clearer 1200/Digging. 2 x in year for each season.
Clothing	45 000	Parents & Family – Dress 10 000UGX, Man's suit 15 000UGX 3 x 10 000UGX & 1 x 15 000UGX = 45 000UGX
Rope	8000	For mat making. 4 made in a year.
TOTAL	344 800	

INCOME SOURCE	INCOME UGX/YEAR	DETAILS
Tea	190 000	10 000 UGX/Month dry season (62kg).Max 20 000 UGX/Month in wet (125kg). Based on 5 dry & 7 wet months. =.1185kg total. Minus contribution to input loan of 30UGX/kg. (kg = 35 550 loan to repay)
Passion Fruit	24 000	500 UGX/week. 12 000UGX so far this year.
Edebbe of beans	6000	3000/Week (Jan & Feb only). 2 sold in a year.
Sorghum	20 000	10000/season (x 2)
TOTAL	240 000	

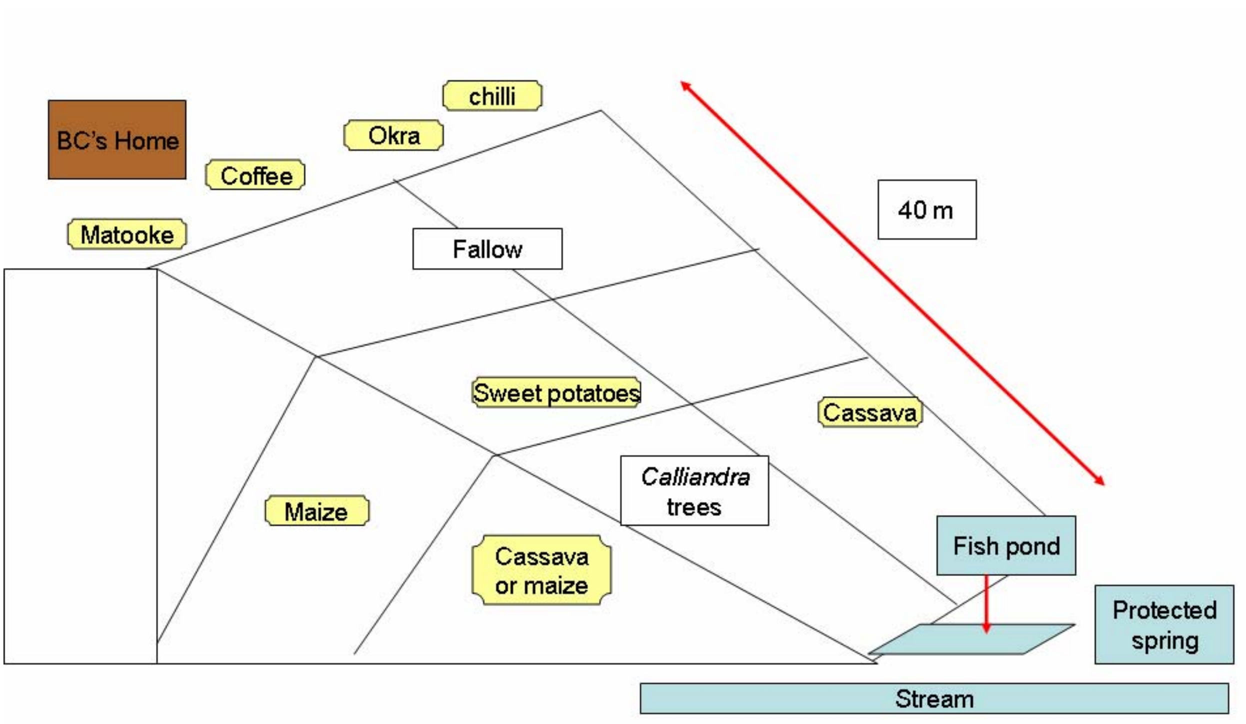
Appendix 9. Shamba and homestead diagrams

Representational cross-sections and diagrams of each case study homestead.

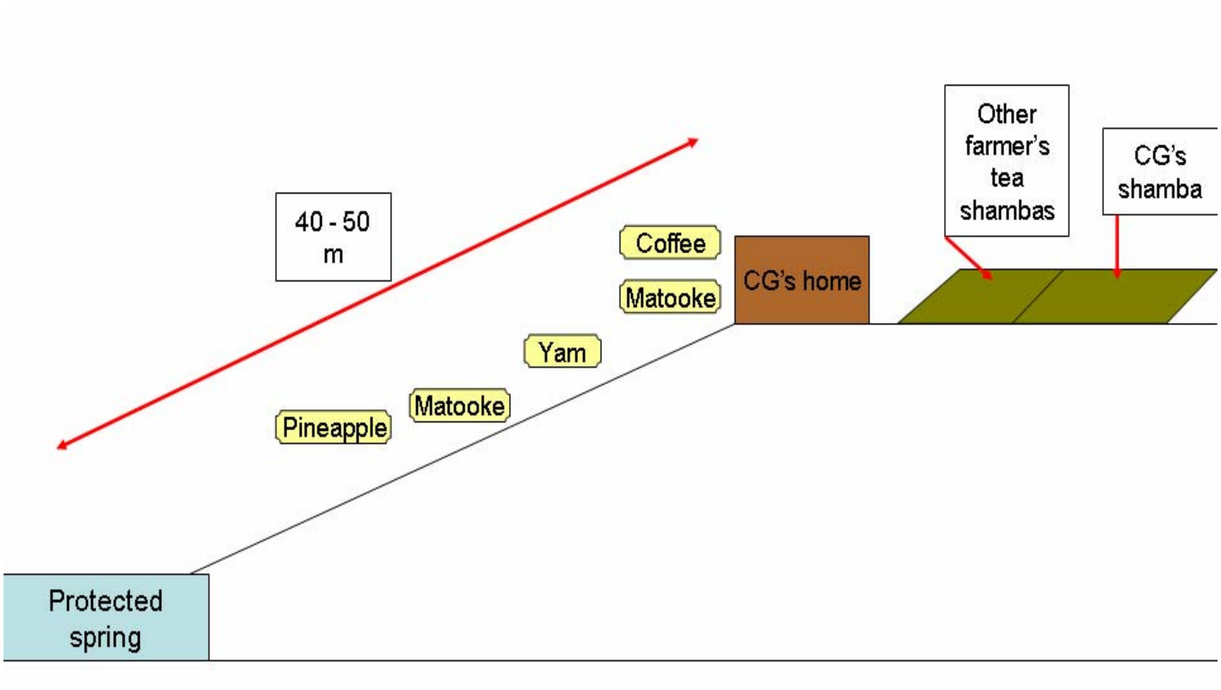
a) AB plot 1 and 2 and homestead.



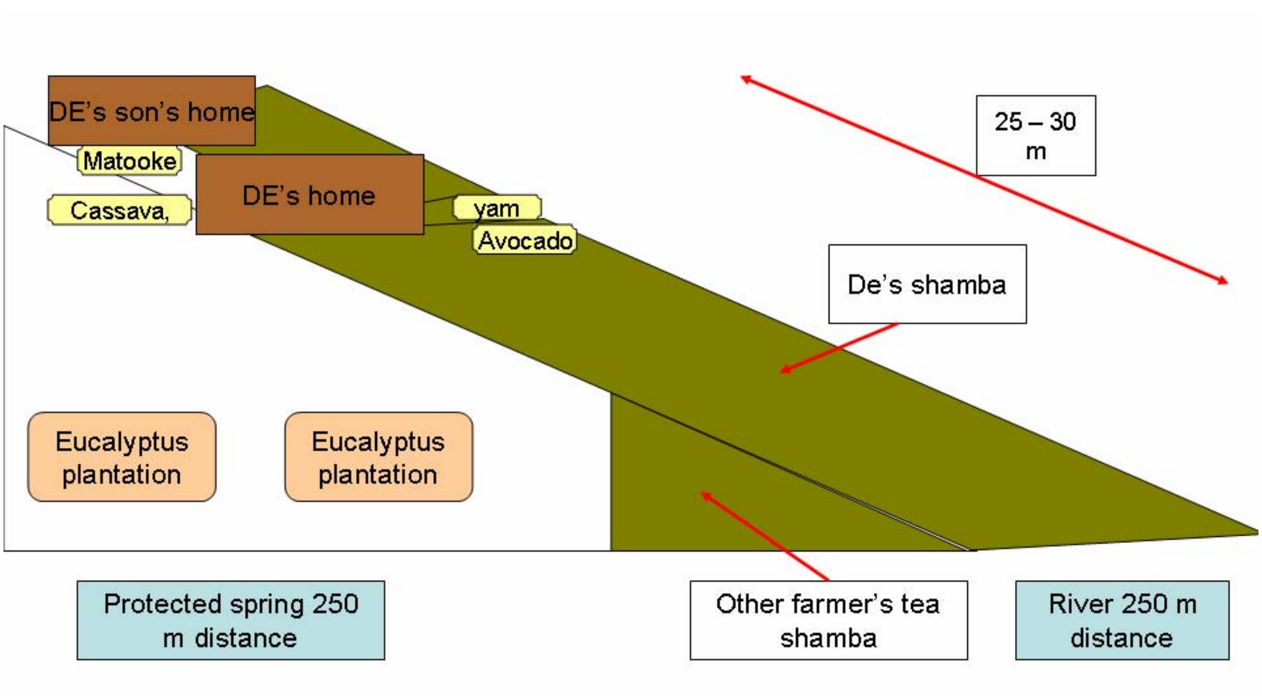
b) BC homestead, other crop cultivation area and water sources. Tea is located other side of home.



c) CG's homestead, tea and water source.



d) DE's homestead, shamba and distances to water sources.



Appendix 10. Irrigation requirements

Water requirements for tea were estimated using rainfall data from the KGTF area using the following equations from (Doorenbos and Pruitt, 1984).

$I_n = ET_{c\ adj} - P_{eff}$ (dep)

Where I_n is net irrigation requirement, ET_c is crop evapotranspiration and P_{eff} (dep) is effective dependable rainfall. A dry season was defined as 2 to 3 months using mean rainfall data (1997 – 2005). Rainfall data from 1997 to 2005 was used to estimate a P_{eff} (dep) of 87 mm during June and July. The mean monthly $ET_{c\ adj}$ requirement was calculated to be 215 mm during this period. Therefore, the net irrigation requirement (I_n) for June and July was calculated to be 128 mm. During the January and February dry season I_n was calculated to be 124 mm. Annual Net I_n amount using the above calculations is 252 mm for tea which translates as 2008 m^3 for 0.4 ha. Using CROPWAT annual net I_n for tea was calculated to be 255 mm.

Gross irrigation requirement was calculated thus:

$Vi = A \times I_n \times 10/Ep$

Where Vi is Volume of water required for period i, A is area in ha, In is net irrigation requirement for the period, 10 converts from mm to m^3 and Ep is irrigation efficiency of the system. A hypothetical efficiency of 50 % is assumed for initial calculations as this represents an average efficiency for a system. Efficiency will be higher or lower depending on the system water losses. An initial area of 0.4 ha or ½ acre was used for calculations. Therefore, dry season irrigation requirements for 0.4 ha of tea are approximately 1024 m^3. Gross irrigation requirements for other crops were calculated using CROPWAT with a 50% Ep.

Appendix 11. Manual calculations of Irrigation requirements for tea.

Penman Monteith	**Kc**	**Eto*Kc**	**Manual calc using USDA formula**	**Etc - Effec Dep Rainfall**	**Etc / days in month**	**0.4**	**p-factor 0.4 * root depth(1.05m) * Available water(200 mm/m) Clay loam**
Eto	**Kc**	**Etc**	**Effec Dep Rainfall**	**Net Irr req.**	**Daily Etc**	**p-factor**	**RAW**
mm/mth		mm/mth	mm	mm	mm/day	%	Mm
110.4	1.00	110.4	51	59.4	3.6	0.40	84
111.4	1.00	111.4	46.8	64.6	4.0	0.40	84
115.0	1.00	115.0	87.4	27.6	3.7	0.40	84
99.0	1.00	99.0	109.2	-10.2	3.3	0.40	84
93.9	1.00	93.9	86	7.9	3.0	0.40	84
101.7	1.00	101.7	46.8	54.9	3.4	0.40	84
114.1	1.00	114.1	40.9	73.2	3.7	0.40	84
112.8	1.00	112.8	87.4	25.4	3.6	0.40	84
112.5	1.00	112.5	133	-20.5	3.6	0.40	84
109.1	1.00	109.1	141	-31.9	3.5	0.40	84
95.1	1.00	95.1	111.4	-16.3	3.2	0.40	84
99.5	1.00	99.5	81.9	17.6	3.2	0.40	84
1274.62		**1274.62**	**1022.8**	**251.82**			

Appendix 12. Crop water requirements and irrigation requirements for other crops

All calculations for other crop water requirements and irrigation requirements were undertaken in CROPWAT.

Sorghum & Beans. Season 1.								
Date	Eto (mm/period)	Planted area %	Crop K_c	CWR (mm)	Total rain (mm)	P eff	Irr. Req	FWS l/s/ha
01-Jan	105.78	0	0	0	0	0	0	0
31-Jan	107.03	0	0	0	0	0	0	0
02-Mar	106.76	100	0.32	19.63	49.02	41.55	0	0
01-Apr	105.65	100	0.32	62.55	79.28	68.61	0	0
01-May	104.38	100	1.02	106.76	74.43	64.92	41.85	0.32
31-May	103.52	100	0.96	99.11	79.79	67.23	31.87	0.25
30-Jun	103.66	100	0.52	32.49	43.8	35.18	0	0
30-Jul	103.66	100	0.33	15.74	60.68	44.87	0	0
29-Aug	104.23	100	0.54	56.05	148.45	107.28	0	0
28-Sep	104.49	100	1.01	105.21	163.47	116.68	0	0
28-Oct	104.01	100	0.99	102.54	157.49	113.66	0	0
27-Nov	102.73	82.14	0.56	40.18	76.73	57.28	0	0
27-Dec	16.97	0	0	0	0	0	0	0
Total	1272.87			640.26	933.14	717.26	73.72	

Sorghum & Beans. Season 2.								
Date	Eto (mm/period)	Planted area %	Crop K_c	CWR (mm)	Total rain (mm)	P eff	Irr. Req	FWS l/s/ha
15-Mar	106.34	75	0.25	26.84	63.31	53.99	0	0
14-Apr	105.08	75	0.6	63	57.17	49.85	13.15	0.1
14-May	103.94	75	0.75	77.95	56.46	48.78	29.17	0.23
13-Jun	103.34	75	0.63	64.92	64.42	52.9	12.02	0.09
13-Jul	17.21	74	0.44	7.49	12.13	9.6	0	0
	435.91	374	2.67	240.2	253.49	215.12	54.34	0.42

		Small vegetables & tomatoes						
Date	Eto (mm/period)	Planted area %	Crop K_c	CWR (mm)	Total rain (mm)	P eff	Irr. Req	FWS l/s/ha
01-Jan	105.78	50	0.52	55.12	44.9	37.36	17.77	0.14
31-Jan	107.03	37.73	0.26	20.69	25.91	21.45	0	0
02-Mar	106.76	68.4	0.44	47.44	59.96	50.64	0	0
01-Apr	105.65	99	0.86	91.24	78.48	67.92	23.32	0.18
01-May	104.38	99	1.08	112.68	73.68	64.27	48.42	0.37
31-May	103.52	87.1	0.92	95.78	68.99	58.29	37.49	0.29

30-Jun	103.31	36	0.32	22.01	22.04	17.72	4.29	0.05
30-Jul	103.66	0	0	0	0	0	0	0
29-Aug	104.23	100	0.65	29.4	67.07	48.16	0	0
28-Sep	104.49	100	0.72	75.71	163.47	116.68	0	0
28-Oct	104.01	100	1.02	105.61	157.49	113.66	0	0
27-Nov	102.73	86.67	0.95	97.34	111.25	83.72	13.61	0.11
27-Dec	16.97	50	0.57	9.76	8.16	6.54	3.22	0.15
	1272.52	913.9	8.31	762.78	881.4	686.41	148.12	

Appendix 13. Rainwater harvesting catchment and reservoir

A rainwater harvesting catchment and reservoir model was created using KGTF rainfall data in order to ascertain appropriate reservoir and catchment sizes for an irrigable area of land of between 0.2 ha to 0.4 ha. A runoff coefficient of 0.3 was used and depth of reservoir was kept at 3 m. Different catchment, reservoir volume, reservoir area and irrigable land sizes were modelled. Figure 49 shows the graph created for a reservoir size of 150 m^3, a reservoir catchment area of 500 m^2 and reservoir area of 50 m^2. Over the course of the 10 years for which the model simulates, 13 % of days are spillage days and 27 % empty days. Although percentage of empty and spillage days are calculated the model does not enable analysis of when these days occur and whether they are concurrent. Combining the model with the SMD models created would enable seasonal storage and irrigation scheduling parameters to be explored.

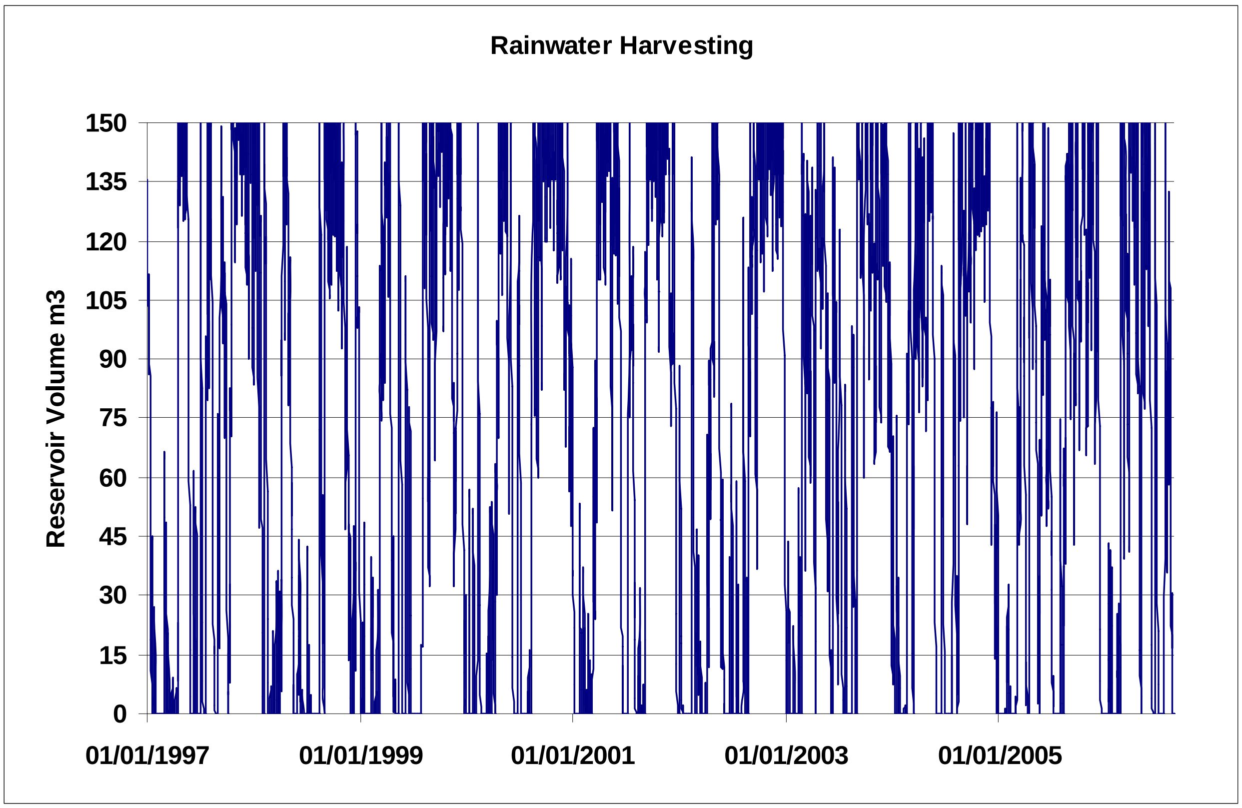


Figure 49. Reservoir model for whole KGTF rainfall record.