Coffee & Climate: The Geometry of Change

A Rapid Diagnostic of Coffee Farmers' Production Challenges in the Mbeya region of Tanzania

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www.coffeeandclimate.org

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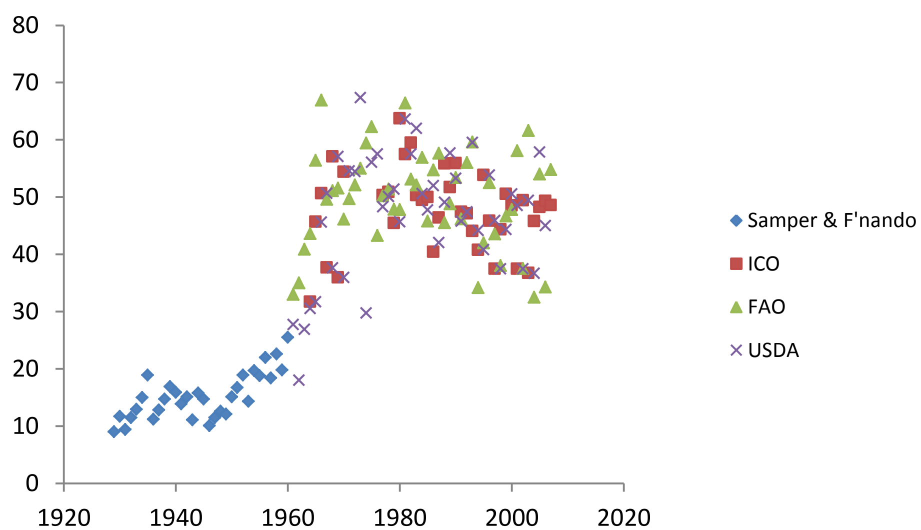
1. Mission purpose

The purpose of the visit to the Mbeya Region (Mbeya Rural and Mbozi), Tanzania, was to initiate studies for the development of adaptation tools for smallholder coffee farmers of this zone. A central principle of the Coffee & Climate Initiative is that adaptation tools must be appropriate to local environmental conditions and coherent with farmers' needs and capabilities. To this end, a programme of work has to be carried out to assess these factors and the visit was a continuing activity of this undertaking, using the methodology described below.

2. Background

After strong growth in coffee growing through the 1960s and 70s, production from the 1980s has been subject to chaotic fluctuations and an overall decline in volumes (Fig. 1).



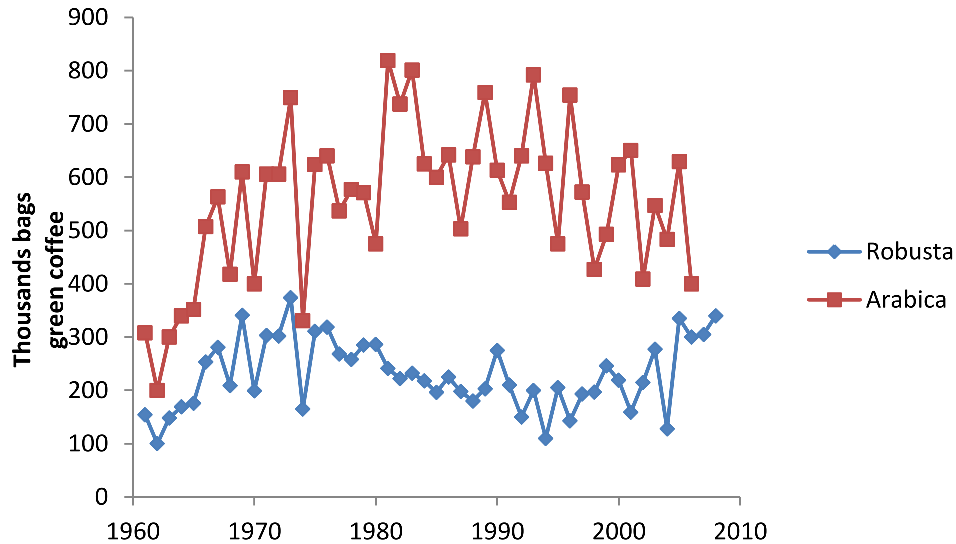


Figure 1. The historical record of coffee production in Tanzania. Above: long term record compiled from four sources. Below: Arabica and Robusta data from Tanzania Coffee Board data.

The widely and rapidly oscillating volumes of Arabica in particular, suggest that climate could be playing a potentially dominant part in this process. A systems engineer, viewing the above waveform emanating from a 'black box', might well conclude that the system is unstable and unlikely to correct itself without a major intervention.

For other crops, Rowhani *et al.* (2011) concluded that in Tanzania by 2050, projected seasonal temperature increases of 2°C may reduce average maize, sorghum, and rice yields by 13%, 8.8%, and 7.6% respectively. In the case of maize, the Global Climate Adaptation Partnership (2011) developed a range of estimates depending on the scenario used. Under more positive climate projections, where rainfall does not decrease, modest impacts are predicted, with even benefits in some regions. However, under some of the more negative high emission projections, where rainfall decreases by up to 15% and there is no adaptation, average maize yields could decrease by up to 16% by 2030 (a loss of around 1 million tonnes/year) and 25 to 35% by 2050 (2 to 2.7 million/tonnes per year). While farm level adaptation would be likely to reduce these impacts, the analysis shows climate change could have very large economic costs, potentially several US$ hundred millions/year (current price, undiscounted). Based on historical datasets, Lobell et al. (2011) calculated that for maize, each degree day spent above 30°C reduces the final yield by 1% under optimal rain-fed conditions, and by 1.7% under drought conditions.

Another report (UNEP 2008) found that the Tanzanian population growth rate was highest in Mbeya rural areas (increase of 132% for 1988-2002) and suggests that such growth has major implications for local water resources.

Finally, satellite spectral data can be used to calculate an index of vegetation intensity i.e. 'greenness' known as the normalized difference vegetation index (NDVI, Vrieling *et al.* 2011). Thus the onset of the rainy season marks a rapid rise in NDVI. By analysis of this data it is suggested that start of the growing season in Tanzania has been delayed by 25 days over 25 years (Fig. 2). This therefore suggests that agriculture in much of Tanzania has already been significantly altered by climate change and in the case of coffee may mean that the trees are more stressed because of a longer dry season.

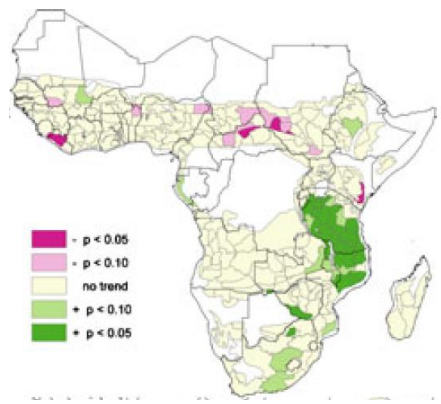


Figure 2. Areas coloured dark green are those where there has been a statistically significant delay in the onset of the growing season (areas coloured dark fuchsia are those where there has been a significant advance in the growing season); from Vrieling et al. 2011).

3. Methodology

The basic approach was a 'triangulation' method to evaluate different sources of information:

- farmers (including farm visits to inspect the state of growing coffee)
- local experts – especially extensionists with detailed experience of the local coffee zones
- available scientific knowledge

If data collected from all these sources is coherent (i.e.has a large degree of overlap), then this gives confidence that our findings reflect current reality, based upon the best possible evidence available (Fig. 3). If the various sources conflict, then further investigations are necessary to discover the sources of any uncertainties.

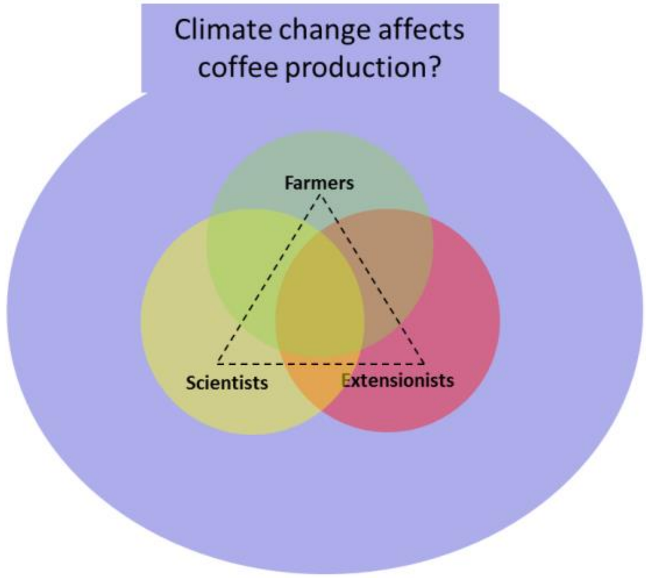


Figure 3. Triangulation: coherence of evidence from farmers, extensionists and scientists on the effects of climate is sought.

4. Findings

4.1 Farmers

This section is a synthesis of findings from present and previous interactions with farmers.

General: A baseline survey (Loisa, 2012) interviewed about thirty farmers from the villages of Shisonta and Idugumbi in Mbeya Rural District. 79% of income is from coffee and there is a heavy dependence on maize and beans as subsistence crops. Farmers all apply some fertilizers, as well as chemical control for both diseases (copper-based products) and pests. Farmers used hoes and herbicides for weeding and applied only sparse mulch. 77% of farmers obtained water from the river, but none irrigated their fields. They reported high temperatures and associated them with severe amounts of sun scorch, flower abortion and leaf wilt. Hail was also a problem, seen also during the present trip (Fig. 4). According to Google Earth, the land around Idugumbi is quite low, not much above 1300 m. The altitude of Shisonta is 1698 m.

Figure 4. Maize damaged by hail storm.

A farmer workshop held at Mbeya Rural Igale Depot (Miyanda, 2012) revealed a wide range of farmer concerns on climate, including:

- Drying-up of perennial streams
- Decline/disappearance of indigenous flora and fauna
- Increased amount of sand/silt in streams and rivers
- Increase in temperatures
- Increase in coffee flower abortions
- Increase in coffee diseases
- Rains coming at wrong times
- Higher wind speeds

Farmers also noted that their activities such as planting times had shifted to conform to the changing weather conditions. Other issues emerging through discussion included: uncontrolled tree cutting, ploughing along river banks and water sources, uncontrolled burning of forests, and uncontrolled livestock grazing, increased coffee pests and diseases, more cases of malaria. Farmers also felt that there was a decline in authority of village chiefs and a need for more community action to deal with these problems – actions such as increased mulching, water harvesting and tree planting.

In a farm to farm survey, where 20 farmers were visited in 14 villages by the HRNS project staff in October 2012 (Miyanda, et al. 2012, farmer interviews) a wide range of problems were elicited through interviews. Disease was the most prominent problem mentioned, mostly Coffee Berry Disease (CBD), with climate coming third and need for irrigation fourth (Fig. 5).

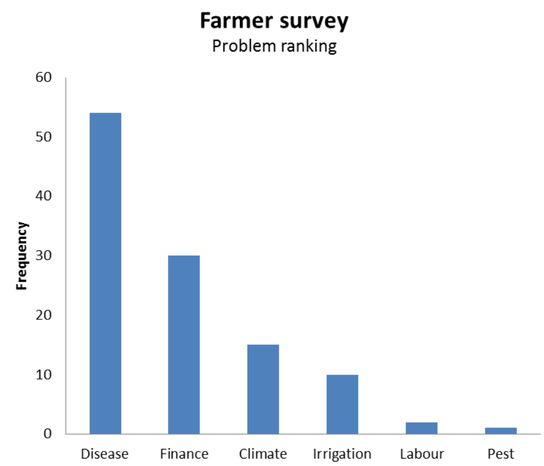


Figure 5. Ranking of farmers' stated problems. Three points were given for first mentioned problem, two for second and one for third.

Farmer meeting at Isuto 28th Jan 2013

During the present trip a meeting with farmers was held at Isuto (c. 1700 m a.s.l.)

The farmers were asked to express their opinions on three fundamental questions:

1. *What are your main production problems?*

A wide range of answers included, in approximate descending order of times mentioned:

- Lack of inputs/expensive inputs/fake inputs
- Lack of post-harvest tools (mostly pulpers)
- Pests and diseases
- Climate: drought, unreliable rains, no specific seasons, more flowerings
- Low coffee prices/late payments/lack of loans
- Poor quality seeds
- Soil testing needed

2. *How have things changed over past 20 years?*

Answers in approximate descending order of time spent discussing.

- Used to have cheap (i.e. subsidized) inputs
- CBD and stem borers have got worse
- Insecticides and fertilizers were better
- Rainfall was better

3. *How do you view the future of coffee farming?*

A wide range of comments included:

- So many problems – we need help
- We need to shorten the commodity chain
- Need more connections to finance
- Loans too risky
- Genuine inputs needed

- Coffee has possibilities if we can get help
- We need to help ourselves more
- Coffee can improve our lives

Generally farmers were more concerned about the business side of farming than climate. It seems that they have never come to terms with the abolition of input subsidies. Since the altitude of this village is 1700 m, it is likely that climatic conditions there are not so extreme and references to CBD, a cool season disease, tend to confirm this.

Individual farm visits (January 2013)
Farms were visited near Utengule, Mkuyu, Itimu and Idugumbi.

In **Utengule**, the 10 acre farm of Edward Fidelis Masawe was visited, which from Google Earth seems to be around 1350 to 1400 m asl. Edward is the chairperson of a local farmers' association.
Yields there were good ~ 10 * 60kg bags/acre. His main problem was lack of labour and input costs. He sprays against rust and CBD and has some problems of aphids and leaf miner. As it turned out, this was probably the best coffee plot inspected during the present consultancy.

Edward said something interesting: "*I don't get flower abortion because I irrigate; my neighbours do not have irrigation and they have flower abortion*." He has a nearby stream and irrigates only once in September. It would be very useful this season to study this activity – how much he applies, his decision criteria, visible effects on the trees, soil moisture, etc. especially if compared to neighbouring farms that do not irrigate.

In **Mkuyu** a farmer called Josta has 2,500 trees, some of them Bourbon variety. Problems include CBD, stem borer, rust and cost of inputs. He sprays fungicide. Maize growing problems include stem borer and a leaf stripe virus. The plot had a very thin layer of maize mulch and a machete or hoe is used for weeding. He complained of rain deficiency some years, and lack of drying facilities. The coffee trees were in fair to good condition, but with a wide range of fruit-load between trees.

In **Itimu**, the farmer expressed problems of CBD, fertilizer leaching through heavy rain, late and poor rainfall. The general state of coffee production was fair to poor, with evidence of rather poor pruning. This plot had shallow basins (10 to 20 cm deep) dug under each coffee tree as a water harvesting technique to pool rainwater and hence encourage infiltration, in a fashion similar to that practiced by Vietnamese farmers. The problem with this technique is that it removes the feeder roots. The tree should recover from this treatment, but because the remaining soil surface had been worked over with a hoe, the loosened soil then tends to fill up the basins after heavy rain and hence must be excavated again. It would seem this technique would only work therefore if the soil is as sticky as Vietnam, or if it could be well covered to prevent soil movement.

At a farm near **Idugumbi** (1431 masl) drought was a key problem ('*rains last year finished in mid-February, used to finish in June'; 'rains start late'; 'water is scarcer than before*'). The farmers all agreed that irrigation was necessary and a good deal of the discussion was spent on how this could be achieved. They also wanted subsidized inputs.

The soil looked poor, with scant coverage of weeds. There was a shade trial (*Grevillea* sp. saplings) that was not going well and might benefit from temporary shade. There were mealybug and/or scale insect problems, possibly aggravated by spraying. A young tomato plot was nearby which looked well-tended. When asked about the problems of growing other crops, the reply was '*they depend on the coffee*' – suggesting that the input costs for producing their food are dependent upon profits from coffee to a greater extent than this consultant had contemplated.

Farmers: conclusions
Of all the farmers met during visits in Brazil, Vietnam, Trifinio and Tanzania, these Mbeya farmers were visibly the poorest and their coffee too was visibly in the worst shape, with a high variance in fruit-bearing between trees and displaying a wide range of defects.

The many problems elicited were difficult to separate and quantify. To what extent were the field problems divisible into lack of/poor quality inputs, old tree stock, accumulations of pest and diseases, soil imbalances and direct climate effects? It was difficult to tell and obviously there is a degree of overlap. A better understanding of the many symptoms seen might be gained by plotting them on a map, to see if they are more prevalent in certain zones and altitudes.

The overwhelming impression of most farms visited was that conditions for coffee farming can only be described as marginal with lack of water as probably the key limiting factor. From a systems or resilience point of view, the farmers seem to be too heavily dependent on coffee and maize. In such marginal farming conditions with few chances of irrigation, this seems a risky situation.

The degree to which climate was seen as a main problem varied, and may be related to locality. In general it would be expected that higher altitude farmers would be less troubled by climate extremes. It is possible too that farmers, having lived under extreme conditions for many years – especially low rainfall, no longer see them as an imminent threat in the way that lack of loans or low coffee prices may be.

4.2 Expert consultations

Extension officer interviews
In October 2012, extensionists were asked a range of questions about climate and coffee growing in Mbeya (Deutsch, Miyanda 2012, Expert interviews). Below are listed a summary of their responses to questions:

Changes in local climate?
- 10 years ago it was cooler
- Less rainfall now than 10 years ago
- Rainfall more variable from year to year
- Pre-rains (Sept-Nov) come late or not at all

Impacts?

- More malaria
- Lower production, light-weight beans, poor quality
- Some farmers now growing cowpea, used to be too cold for it
- More poverty but farmers still keep their coffee

What are farmers doing?

- Farmers drilling for water (unsuccessfully)
- Asking for irrigation
- Applying mulch, they fear fire, but see advantages
- Lack knowledge, do not know what to do
- In next 10-15 years, farmers will abandon their fields if no intervention

What do farmers need?

- More training
- Soil moisture conservation measures (mulch)
- New varieties (fast-maturing, disease resistant)
- Irrigation/boreholes drilled
- Water harvesting techniques
- Restrict tree cutting/plant more trees

Stakeholder meeting 30th January 2013 (Mbeya Catholic Centre)

After a plenary session, with an introductory talk on coffee and climate in Tanzania, participants were split into four groups to discuss in detail four potential adaptation methods or 'tools'.

Results of the group discussions focusing on four different climate adaptation methods

Group 1, topic: Soil Cover

Suggestions

1. Using slashers instead of the weed selector
    - Soil cover is provided and this method can easier be adapted by farmers
    - Participants proposed to test the weed selector in demo plots by interested farmers.
2. Mulching

The group suggested mulching as an important soil cover method and advised to use the following mulching materials:

- Maize stalks
- Banana plant leaves
- Grasses, which have been planted in between coffee rows and slashed to serve as green mulch

3. Using live mulching materials

Group members suggested plants like desmodium (Kiswahili: mkuna) to be used as live mulch (cover crop), since desmodium plants support soil fertility.

Group 2, topic: water management
Suggestions:

1. Digging water harvesting basins in coffee fields, in order to increase soil moisture.
2. Digging water wells for irrigation purpose to help with coffee flowering purposes. Some farmers are already using this method.
3. Protecting water sources by leaving natural vegetation along river banks undisturbed (to reduce erosion).
4. Planting water protecting trees along and near water sources, e.g. example *Ficus* spp (Kiswahili: mkuyu) as water protecting trees.
5. Protecting available natural forests and planting new trees.
6. Using bottles for irrigation, as example of drip irrigation to use water economically.

Further suggestion and comments

- The introduction of demucilator/ ecopulper machines shall be further evaluated.
  [Comment: After the presentation of the demucilator the stakeholders were very interested in this technique under the assumption that less water is needed for pulping. However, further evaluation is needed because the water mixed with mucilage cannot be recycled.]
- Digging water basins between trees and coffee plants for water harvesting.
- Question: Which kinds of trees are good for rainfall attraction?
  [Comment: It is advisable to plant trees that are taller than the tallest structure of the farm land to help with wind breaks and support conventional rainfall in rain seasons.]

Group 3, topic: The use of gypsum, hydrogel and mycorrhyzae
Suggestions:

1. These new technologies have to be tried on demo plots and when they work the technology should be spread to all farmers where it is appropriate.
2. To mitigate climate change impacts, farmers are advised to continue use of mulching, shade trees, irrigation, and cover crops

Further suggestion and comments

- Use of well blended fertilizers which contain base elements like magnesium, potassium, phosphorous, and calcium which help to increase more roots. These fertilizers should be used while the other technology is under testing in demo plots.

Group 4, topic: Temperature management
Suggestions:

1. Tree planting, using trees which conserve moisture require small amount of water to survive and correspond to our environment
2. Using soil cover plants like *Desmodium* spp (mikuna)
3. Planting of good shade trees, e.g. *Acacia* spp and *Leucaena* spp
4. Planting wind control trees around the farm (depending on where wind comes from)
5. Inter-cropping (e.g. banana with coffee as diversification)
6. Planting water conserving trees, e.g. *Ficus* spp (mikuyu)

Visit to TaCRI Mbimba Sub-Station, Mbozi (31st January 2013)
Isaac Mushi, zonal Programme Manager told us that Mbeya district is now the largest coffee producing zone of the country, accounting for 25% of production. The weather is changing however – used to get rain last week of September or first week of October, then rains continued until last weeks of April or into May. But now, there is little rain up to December. Last year rain came in second week of November and production is down. The rainfall is not reliable. The dry season is now so intense that coffee on the station sheds much of its leaves by the end of it.

In Mbeya Isaac said, coffee quality is a problem and clean water is an issue.

He and his staff are trying to encourage farmers to plan shade trees, especially *Albizia* spp. and *Cordia africana*: '*an agroforestry system protects the coffee giving more moisture*.'

He said that it is a myth that new clones' root systems are poor. But you do get overbearing with the new variety, it develops very fast.

A local experience with water harvesting: a big estate nearby installed 90 acres of drip irrigation fed from a dam; last year however, the dam was dry.

Boreholes are also mostly not working because of the very low water table.

It is hard to advise farmers now on specific activities, he said, because *'we don't know when the rains are coming.'*

Isaac was very willing to collaborate and some joint project activities could be fruitful.

Isaac was familiar with Moshi – formerly a major coffee zone – now, he said: '*you can't believe the temperatures there … when I grew up there, the rivers were full*'.

Summary of expert inputs
Experts agree on the seriousness of the climate change threat to coffee production. The need for water conservation measures was frequently mentioned, as well as an improved water supply. It is also clear that many experts believe in the utility of shade/companion trees to protect the coffee plants and conserve water. Potentially these experts could help the project to locate field situations where trees and coffee are together prospering under extreme conditions.

4.3 A review of scientific knowledge of climate change as it relates to coffee in Mbeya

Temperature
For Tanzania as a whole, mean annual temperature has increased by 1.0°C since 1960, an average rate of 0.23°C per decade. This increase in temperature has been most rapid in JF and slowest in JJAS (McSweeney 2005).

At first sight, temperatures for Mbeya seem very mild, with an historical mean annual temperature of 17°C, which is slightly lower than the usually stated temperature range for Arabica of 18 to 22°C. Also, from the recent NAPA report (United Republic of Tanzania 2012) the Mbeya region seems to be the coolest extended zone in the country (Fig. 6). However, these are mean temperatures and disguise a large min-max range (Table 1).

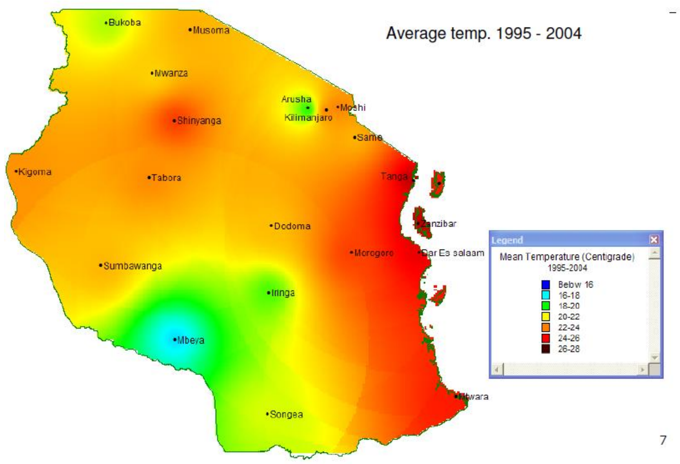


Figure 6. Mean temperature map from the Tanzania NAPA report (United Republic of Tanzania 2012)

Mbeya (1700 m asl)	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Temp	17	17	17	17	17	16	14	14	15	18	19	19	19
Mean Max Temp	23	22	22	22	22	22	21	21	22	25	26	26	25
Mean Min Temp	11	13	13	13	12	11	8	7	8	11	12	13	13
Mean Precipitation	850	190	150	150	110	10	---	---	---	---	10	50	130
Highest Recorded Temp	31	27	30	26	26	26	26	26	28	31	31	31	30
Lowest Recorded Temp	2	10	10	7	8	5	2	2	3	6	7	8	10
Mean Rainy Days	55	10	10	9	7	1	---	---	---	---	1	4	9
Mean Relative Humidity	68	78	77	78	77	71	66	62	59	55	56	60	72

Table 1 Historical data (29 years) from the Mbeya met. station (www.weatherbase.com)

Of particular concern to coffee growing are high maximum temperatures and a map of this (Fig. 7) indeed shows evidence that extreme temperatures (around and above 32°C) probably include coffee areas, though a detailed map of Mbeya coffee areas is currently lacking and the map below must be approximate only.

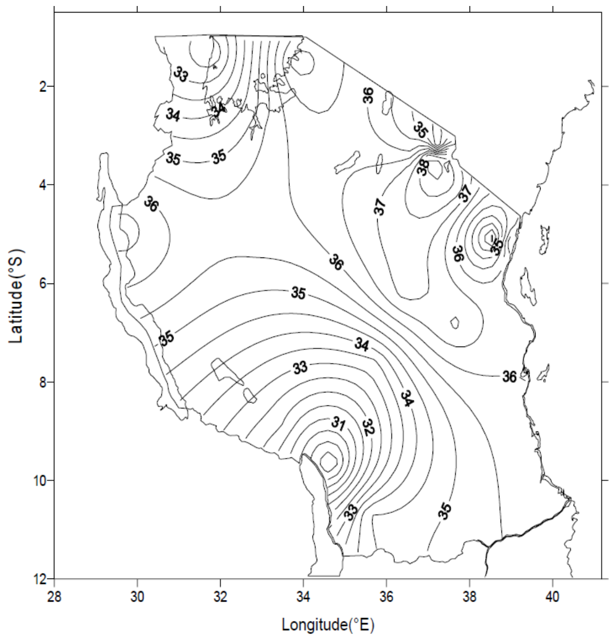


Figure 7. Extreme Maximum temperature map of Tanzania (United Republic of Tanzania 2007)

The highest recorded temperature for Mbeya is 31°C, but since this station is located at 1701 m above sea level, this means that the coffee around Utengule for instance (1350 to 1400 m asl according to Google Earth) and several other villages visited, would be around 2°C hotter; coffee visited around Idugumbi seems to be even lower. Hence maximum temperatures around and above 32°C are entirely possible and significantly, occur during the flowering season making them liable to induce flower abortion.

Corroboration comes from Jack (2010), who suggests at least one >32°C day in November is possible for Mbeya (Fig. 8) though it is not clear how he estimated this. Because temperatures will inevitably rise in coming years, the risk of very high temperatures will increase and it would be very useful if these risks could be estimated. Reports of flower abortion in the field are therefore likely to be caused by these high temperatures, or drought stress, or a combination of the two.

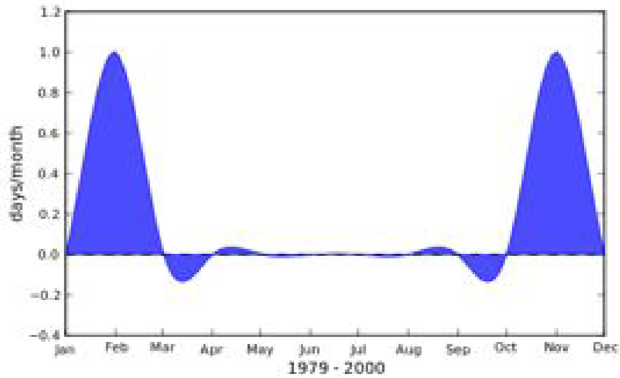


Figure 8. Monthly climatology of days exceeding 32°C in each month for Mbeya (Jack, 2010).

Temperature outlook: for Tanzania, the mean annual temperature is projected to increase by between 1.0 to 2.7°C by the 2060s (McSweeney 2005). Lack of global mitigation activities to date strongly suggests that lower estimates are now very unlikely, hence a 1°C rise over the next 20 years seems very possible.

Precipitation

According to McSweeney (2005) rainfall over Tanzania shows a statistically significant decreasing trends in annual, and JJAS and MAM rainfall. Annual rainfall has decreased at an average rate of 2.8 mm per month (3.3%) per decade. The greatest annual decreases have occurred in the southern most parts of Tanzania. MAM and JJAS rainfalls have decreased by 4.0 and 0.8 mm per month per decade, respectively (3.0% and 6.0%). There is no statistically significant trend in the proportion of rainfall occurring in heavy events. 1- and 5-day rainfall maxima show small, non-statistically significant decreasing trends. 5-day events show a significant increasing trend of +11.03mm per decade in MAM.

Precipitation is a key variable of interest to coffee growing. The mean annual rainfall for Mbeya is only 850 mm (Table 1) making it marginal for coffee production. How much mean rainfall varies across the region, e.g. due to mountain ranges, is unknown however. There can be great variation in rainfall from year to year (Figs. 9 & 10). Rainfall is very concentrated, so that much of the Mbeya district could be without any appreciable rain for 6 months of the year (Fig. 11). Because of expected increases in temperature (and therefore evaporation) and no immediate expectation of improved rainfall in coming years, this can only imply that an already marginal climate for coffee growing will become increasingly so.

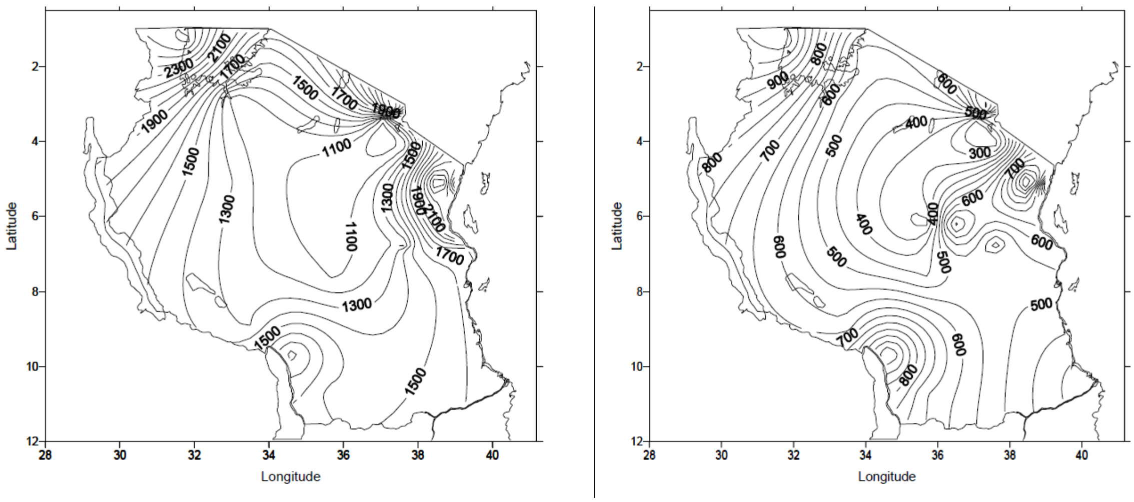


Figure 9. Extreme high and low precipitation map (mm rain/year) for Tanzania over time span of 1921 to 2005 (United Republic of Tanzania, 2007).

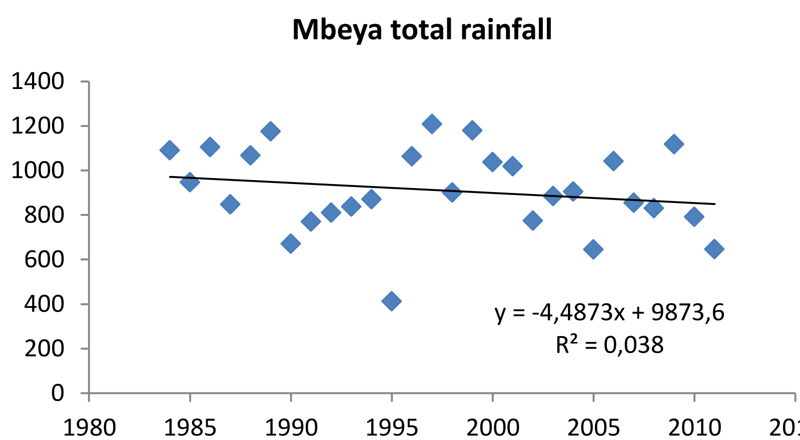


Figure 10. Mbeya rainfall displays wide variation between years. 25% of years had rainfall below 800 mm, which is extremely low for coffee. There are slight signs that rainfall is declining.

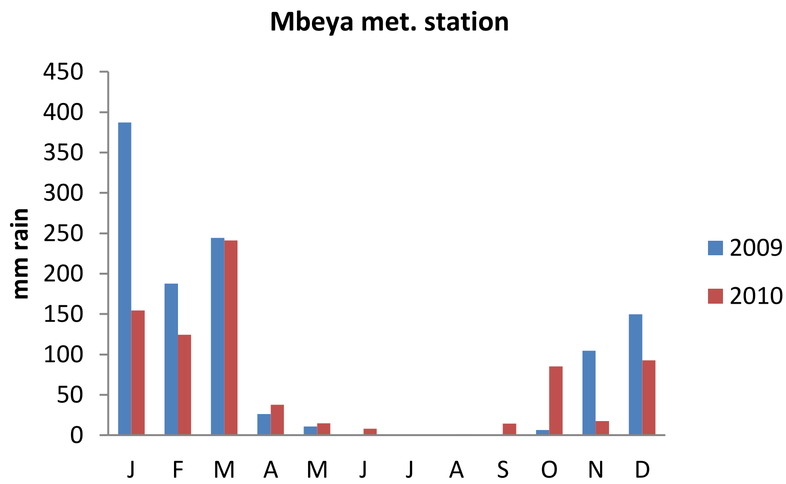


Figure 11. Rainfall varies widely from year to year, with a long intense dry season and sometimes a stuttering start to the wet season.

Precipitation outlook: projections of mean rainfall are broadly consistent in indicating increases in annual rainfall. The ensemble model range spans changes of -4 to +30% by the 2090s, and ensemble median changes of +7 to +14%. The models consistently project overall increases in the proportion of rainfall that falls in heavy events. The increases range from 1 to 14% in annual rainfall by the 2090s. Increases affect most of the country in the seasons JF, MAM and SON. The models consistently project increases in 1- and 5-day rainfall maxima by the 2090s of up to 24mm in 1-day events, and 4 to 37mm in 5-day events. The largest increases are seen in MAM.

However, as Tierney *et al.* (2013) very recently point out, although present climate models predict that East Africa will get wetter with global warming, the region has in fact become drier in recent decades. They suggest that the discrepancy could be explained by a naturally occurring dry period and put forward some quite convincing data that variations in the sea surface temperature gradient across the Indian Ocean—which alter the Walker circulation—seem to be exerting an important principal control on the hydroclimate of East Africa over multi-decadal timescales.

The pollen record from Lake Masoko a small maar lake in the Mbeya region corroborates the existence of such long-term secular changes (Vincens *et al*., 2003).This record provides evidence that wetter Zambezian woodlands occupied this area during the late Holocene, reaching a maximum extent between 2800 and 1650 BP. However, these were interspersed with three main episodes of decline, between 3450-2800 BP, 1650-1450 BP and 1200-500 BP, for which a climatic interpretation (decrease in the summer monsoon strength) was advanced.

In other words, there may well be a range of influences, that include GHG-driven global warming, as well as cyclical oscillations driven by oceanic warming and cooling, that are of more than one frequency. How these interact over the short to medium term seems at present to be very uncertain. Hence there should be no expectations that a hoped-for wetter climate will come soon to Tanzania and coffee adaptation should proceed under that general assumption.

Overview of climate data

Now: The apparent temperate nature of the Mbeya climate, as revealed by its annual temperature of 17°C, disguises some disturbingly high maximum temperatures, which together with low and concentrated annual rainfall, plus a great deal of inter-annual variation, make coffee in this zone a rather more marginal crop than might be imagined. A concern is that these variables, which have been getting less favourable for coffee over recent years might now be approaching a tipping point.

A present difficulty is lack of precise data on where coffee is grown and climatic data for these places. To an extent we should be able to construct approximate temperature maps based on height variations, perhaps relate to any available satellite spectral data (NDVI) and even an educated guess about how rainfall might vary from the recorded values of the Mbeya station. However these will need to be corroborated by locally collected data, especially around the critically important period of transition from dry to wet season (Oct-Nov). A combination of visual assessment of drought (degree of wilting, scorch, abortion) together with measurements by handheld thermometers (especially max temps between 13.00 & 15.00(?)) and collection of soil samples for moisture determination would help to build a picture of how extreme conditions really are and confirm where the danger areas lie.

One alternative, where met data are scarce is the use of remote sensing data sources. Can minimum and maximum temperature from land surface temperatures coming from the MODIS Aqua and Terra sensors be sourced? Daily data of these sensors is globally available from 2000 onwards at the 1km resolution. Further examination of vegetation indices (also coming from MODIS sensors) and altitude data might be studied? The few ground data available can be used to calibrate the generated high resolution data? There may be only 13-15 years of data from these sources, but they could be useful to study the relationship between coffee production figures and weather in Tanzania and other countries with scarce met data?

Reanalysis data, mainly the ERA Interim product from ECMWF might also be an option? (http://www.ecmwf.int/research/era/do/get/index) It offers met data from 1979 at 0.75 degrees resolution.

The future: all climate models suggest that temperatures will continue to increase strongly in the coming years and it is possible that dry-wet season precipitation patterns might become even more pronounced than they already are. A combination of virtually zero rain for 5+ months and rising temperatures suggests that a principal concern for coffee and all agriculture in Mbeya will be lack of soil moisture. There is no reason to suppose that the region will become wetter any time soon, hence for any long term future that includes coffee, some form of irrigation will be increasingly necessary.

The recent comprehensive report on the economics of climate change in Tanzania (Global Climate Adaptation Partnership, 2011) found that Tanzania is not adequately adapted to deal with existing climate risks, let alone future ones. The report calls for robust strategies to prepare for the future, rather than using uncertainty as a reason for inaction.

The meteorological data for this zone is scant and hence it will be important to expertly review the evidence and make the most of it. It is to be hoped that the Met. Department of the University of Reading (through an MSc. studentship) can assist with this process to make sure the correct inferences are drawn.

4.4 Overview of triangulation evidence

There is broad agreement between farmers, extensionists and available scientific data that the Mbeya zone is becoming more marginal for coffee growing. Visual inspection of coffee fields suggested a wide range of problems, some/many of which are likely caused by these marginal and increasingly extreme conditions. There is a little-known law of ecology called Schmalhausen's Law which proposes that when a system becomes stressed towards the edge of its tolerance in regard to one variable (e.g. high temperatures) it will become more vulnerable to small changes in any other aspect (e.g. pests and diseases). What is happening in Mbeya may be a manifestation of this 'law'.

However farmers do not always mention climate problems prominently. This might be because:

- they have very pressing economic worries (likely because yields are so low, the coffee can hardly be very profitable);
- the climate has been extreme for so long that they are already adapted and prepared for it to an extent;
- in some localities the climate is less extreme.

The last point is a difficulty that needs to be overcome – at present it is hard to understand and visualize:

- Where the most marginal coffee is (mostly low altitudes?)
- Where current demo plots are (do they fully represent the coffee zone?)
- Where the various reported problems are (do they cluster on the map, or are they random?)

Activities discussed below should help to remedy these conceptual difficulties.

5. Specific themes

The complexity of the situation requires some further considerations which are dealt with here under separate headings. What follows can be considered as background thinking and justification for the tools suggested in Appendix 3.

Marginality

Descroix & Snoeck (2009) suggest that for Arabica coffee, prolonged exposure to temperatures above 30°C incur leaf chlorosis and generate star flowers, abortion and defective fruit set. They also state that rainfall of less than 800 mm, even if well distributed (in Mbeya it is not) can be hazardous to coffee productivity. Arabica they assert however can withstand up to 6 months drought if the soil is deep and affords good water retention. Generally they suggest that where rainfall is below 1100 mm, irrigation will be needed.

A long term study from Costa Rica (Fournier & Di Stéfano, 2004) on coffee yields vs. climatic variables, the only known one of its kind, found the highest correlation to yield with level of precipitation during the dry season (Dec-Apr), and mean maximum temperatures during the same period (Fig. 12). The clear inference from this study is that intense droughts and high temperatures are inimical to good harvests.

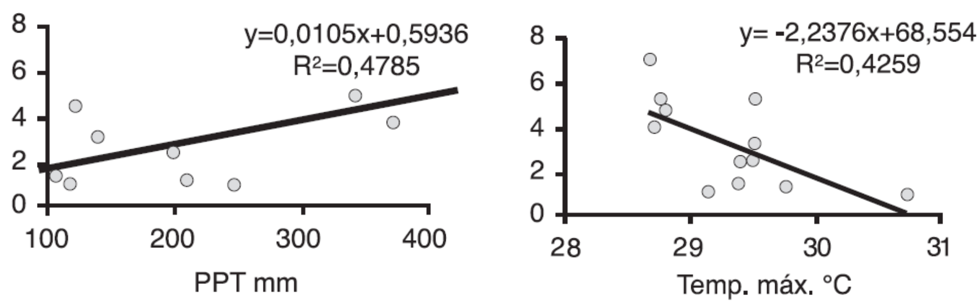


Figure 12. Production levels (relative volumes on scale 0 to 10) of a coffee farm in Costa Rica (750 m asl). Left: total dry season precipitation. Right: mean maximum dry season temperature (Dec-Apr); from Fournier & Di Stéfano (2004).

From the above, because of high maximal temperatures, paucity of annual rainfall as well as length and intensity of dry season, coffee growing across much of the Mbeya region must be regarded as 'marginal'.

A major problem is that the solution for high maximum temperatures – shade trees – may well be confounded by the lack of soil moisture to support them. Shaded coffee was seen at 1700 m around Isuto and seems compatible with coffee there; however we do not know how well this might work at lower altitudes where shade would be most needed and evapotranspiration more extreme.

Adaptation and maladaptation

Clearly drought is a major concern for all but the few who are close to a reliable water source. Although we hope that Tanzania becomes wetter in the future, this is by no means certain, nor may it mean more reliable rainfall when it is most needed. Because of the inevitability of rising temperatures as well, it seems most likely that drought will remain a major concern and could well get worse.

Hence any solutions (tools) that do not confront the central problem of water scarcity, risk falling into the trap of maladaptation. I.e. the project can recommend tools that might help in the short term (e.g. mulch), but if the long term prognosis is more extreme climatic conditions, these tools will ultimately not be of much help. Some uncomfortable reckonings and decisions will have to be taken about which farmers can be helped to continue in coffee for a number of years and which could be helped more by assisting them to diversify into other hardier crops.

Remaining time under the existing project does not permit a comprehensive approach to the drought problem, but serious consideration should be given to further assessing the feasibility of the various ways to harvest water, store it and use it efficiently. Whatever the future of agriculture in this region, farmers will need more water and any prospective projects will need to provide convincing evidence that a wide range of water-supply possibilities have been well scoped and costed-out.

However much knowledge, planning and hard work is put into this project, lack of water will seriously compromise success.

High temperatures

Reports of flower abortion are especially worrying, because if these are indeed linked to high maximum temperatures during the flowering period, we have almost 100% certainty that this problem will get worse. From the literature, it seems that abortion gets progressively worse as temperatures rise further above 30°C; less understood is how this could be influenced by other factors, especially the degree of stress of the tree after an intense dry season.

The data is lacking to get an accurate picture of how much of the Mbeya coffee zone is already suffering. I.e. what percentage of the coffee zone is affected by leaf scorch, severe wilting, leaf drop and flower abortion through the transition from dry to wet seasons? How are these variables affected by altitude, soil type, variety and age of tree?

It will be important therefore to get a more comprehensive assessment of these problems in order to map out the most affected areas. There should therefore be some initial reconnaissance work to identify and map these areas (from farmer and extensionist interviews) followed by an intensive data collection period through the dry-wet season (Oct-Nov?) to visit areas in and around putative problem zones to collect first-hand visual data of leaf wilt, leaf scorch, flower abortion etc. and make soil humidity and max temp measurements.

Towards a zoning scheme

Results from suggested field work can help formulate some ideas about the extent of the problems and proximate causes. Hence certain temperature ranges, slope orientations and soil types together may be causing extreme difficulties and indeed some farmers may already have abandoned coffee production.

From this, with collaboration from meteorologists (Reading MSc student?) it may be possible to overlay problem areas onto maps of maximum temperatures, AND rainfall etc. Additionally, with a weather generator and different temperature scenarios, we might be able to estimate the future frequency of occurrence of extreme temperatures and where these might be most likely.

The outcome of this work would be to develop some approximate zones to orientate future field activities, e.g.:

- **Red zone**: good evidence of major stress to trees in dry season with leaf scorch and flower abortion. Diversification and staple crop yield improvement would be major activities here;

- **Yellow zone**: some stress but few signs of catastrophic yield loss – major adaptation activities here;

- **Green zone**: only intermittent climate problems; intensification is the main goal.

Shade

Shade is the only answer to high maximum temperatures and because of its potential seriousness, finding and trialling compatible shade trees becomes a priority; even though this will obviously be a long term initiative and may well depend on the extent to which irrigation can be provided as well.

Preliminary results of a shade study by TaCRI (2008) were not encouraging (Fig. 13). More details of this trial are not known, nor whether it was continued. Enquiries should be made by HRNS staff to find out more about the fate of this trial, where it was carried out, type of shade tree etc. to see if there are any broad lessons to be learned.

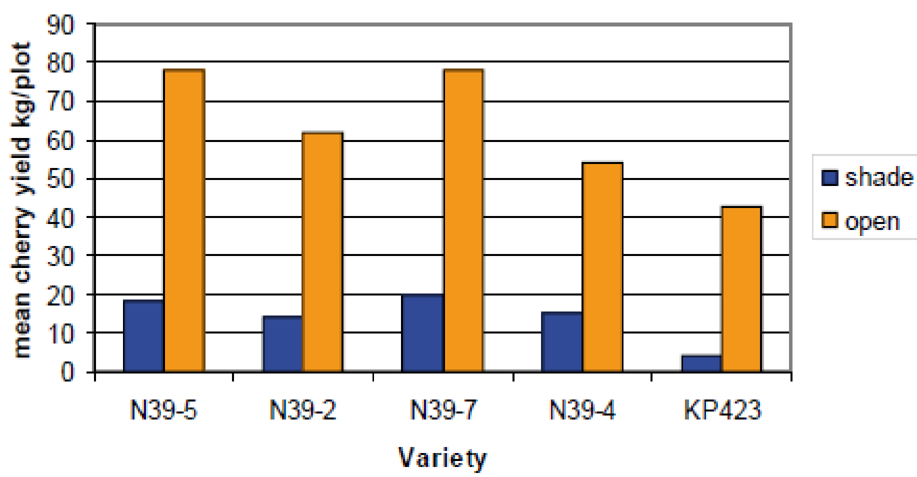


Figure 13. Results of a TaCRI shade trial (TaCRI, 2008).

Additionally, examples of plantations using shade and irrigation (such as exist in Arusha Fig. 14) could be visited to estimate costs of this increasingly necessary procedure, perhaps as part of a future irrigation/water harvesting consultancy.

Figure 14. Irrigated and shaded coffee, Tuvaila, Arusha (2006). This coffee is at c. 1200 m, shade here is probably essential because of risk of high maximum temperatures.

Shade observations: the only short-term way to advance understanding is through field observations of coffee in shade and un-shaded plots, preferably where the two stand side-by-side.

Because rainfall is so low, there is a strong likelihood that effective shade, which might reduce maximum temperatures by up to 4°C or more, would compete for scarce soil moisture with coffee trees. This assertion should be tested by trying to find lower altitude coffee (say, 1350-1500 mm) with substantial shade and where the coffee looks in good shape and productive.

From the extensionists meeting (Section 4, above), it was felt that there could be some candidate trees that would furnish shade yet not compete too much with coffee. The project should therefore vigorously follow up on all possible leads of this sort, to find out whether indeed there might be a compatible shade tree that performs well with coffee in hostile conditions. Indeed for the present project, all that can be done is to identify and study a range of field experiences (good and bad) from which to develop experience, ideas and hypotheses for future long-term adaptation field work.

Farming systems

The current farming system in Mbeya is heavily dependent upon Arabica and maize. Authoritative evidence suggests that both these crops become progressively stressed above 30°C (Descroix & Snoeck, 2009; Lobell et al. 2011). Because temperatures regularly rise above this level in the study zone and because they are certain to rise further in the future, it does not seem sensible to rely so heavily on two crops that display such similar sensitivities. Some serious consideration therefore needs to be taken concerning the viability of the current farming system. There is a *prima facie* case here that farmers should be encouraged to try alternative crops – e.g. millet, cassava.

Quick-start activities

It is important to get some field trials going and collect more field experiences.

Resilience building: the general state of coffee seen during this trip was quite poor. Per-tree coffee production was often very heterogeneous, it being not uncommon to see well-laden trees interspersed with virtually barren trees. The reason for this is not understood. Other plots looked more uniformly poor, with yellow-pale green leaves suggesting nitrogen deficiency, though this might be related to high temperatures causing chlorosis. There were a number of other defects and pest problems too. The Technoserve project has identified two major soil deficiencies for the Mbeya region: zinc and boron. Some of the leaf defects noted during the present trip are consistent with this diagnosis (Fig. 15); symptoms of iron deficiency were also seen and this might indicate also a pH problem.

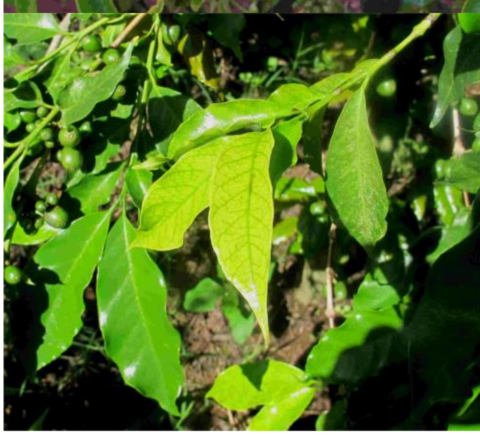


Figure 15. Zn, B and Fe deficiencies were not uncommon

Soil testing: for all plots therefore a general health check is suggested, starting with a pH test which is simple and cheap to carry out. Technoserve results suggest that low pH in Mbeya is not a major problem, and therefore that liming may not be needed, but some sampling should confirm this. A few full soil and foliar tests would be very useful too, in order to confirm the general state of the soil and the most probable deficiencies. Because of the extreme nature of the climate, it is imperative that soils are in the best possible condition.

Compost: maize stover and other residues including coffee pulp are quite abundant, though much of it will be fed to livestock. Making the most of available residues in order to build up durable soil organic matter is another priority. Some study of farmers' current composting activities should be carried out – how do they do it? Could it be improved?

Stress test: because of the extreme climate in the zone, it is suggested that a stress test is developed to measure general stress of coffee trees, especially through the second half of the dry season into the wet season to see how quickly they recover (roughly July – December). Measurements would include measurement of degree of wilt (a visual scale should be provided), incidence of leaf scorch, leaf drop and flower abortion. Measurements of soil moisture and ambient temperature during field visits should also be taken.

Mulch experiments: Mulch tests are already contemplated and should be carried out considering the following points:

- Test different depths of cover e.g. 5, 10, 15 cms.
- Measure temperature over and under mulch
- Measure soil moisture for experiments and control.
- Measure rate of deterioration of mulch
- Evaluate SOM at start and finish
- Test different sources of mulch (if available),

Start – end of wet season
Finish – end of dry season

Water harvesting: in-field *w*ater harvesting around individual trees seems to be problematic. The idea is to pool water around the tree after rain storms to reduce run-off and increase infiltration. This is accomplished by excavating small basins around the trees to a depth of some 10 cm or more. However this hollowing out under the tree removes feeder roots and because the depressions tend to fill up quickly again with soil that is moved by heavy rain, they have to be re-excavated. It would seem that this basic water harvesting arrangement (commonly used in Vietnam) can only work well if the soil is protected by a ground cover of some sort to reduce such soil movements. Hence ground cover trials should be carried out (see below).

Internal capacity building on water issues: water is so scarce that it seems certain that more activities to collect and irrigate will be required. Hence serious consideration should be given to finding a consultant (preferably with experience of the region) who can assess the options for each locality and assign likely costs. Evidence of other water harvesting and irrigation projects in Tanzania should be searched for and visited if possible (see Appendix 1 and Fig. 16).

Figure 16. Lined pond, Arusha 2006. Information should be collected on cost-benefit of these.

Ground cover: ground cover is doubly important, both to retain soil moisture during the dry season and facilitate the water harvesting and infiltration during the rains without siltation. This can be developed by:
a) collecting and planting out one or two candidate low-growing cover plants in test plots to study their growth and effectiveness.
b) using a weed-wipe (weed selector) to discourage fast-growing graminaceous weeds and thereby select for low growing and spreading weeds.

Such experiments could yield useful initial results within a season.

Whatever the outcome however, as a general rule, the use of hoes in coffee plots should be discouraged. They provoke soil erosion and can also spread disease between trees.

6. Managing risk

Risk = Hazard * Vulnerability

As frequencies and intensity of climatic hazards increase due to climate change, farmers' vulnerability must be reduced in order to maintain risk at constant levels.

Vulnerability = Sensitivity * Exposure – Adaptive Capacity

Vulnerability here can refer to the coffee/shade plots, as well as more broadly to farmers' livelihoods and infrastructure.

Sensitivity here means how any element of the system responds to climate – e.g. for rust the coffee plant is highly sensitive to increased humidity at key points in its cycle. Sensitivity could be reduced by planting a resistant catimor variety that is less sensitive to infection.

Exposure for example means the degree to which the coffee plant is exposed to high humidity. This is more difficult to control, but could be altered by reducing shade in some circumstances, though this would increase exposure to other weather variables.

Adaptive capacity means the resources and knowledge of farmers and support institutes to take the right action, e.g. apply prophylactic copper sprays in a timely and efficient manner.

Clearly then, to reduce vulnerability and therefore risk, sensitivity and exposure should be reduced and adaptive capacity of farmers increased. Table 2 resumes some of the risk factors and likely activities to reduce them.

Factor	Sensitivity	Exposure	Adaptive Capacity
High maximum temperatures	Are some varieties more sensitive than others? Is drought-stress a contributing factor?	Shade can reduce maximum temperatures by 2°C or more. But competition for soil moisture could be a major problem	Research: need more data on extent of high temperatures, especially during the next flowering season.
Coffee leaf rust and berry disease	Resistant varieties are available, but some are clonal, so root system may be inadequate for extreme drought conditions		Research: evaluate efficiency of available spray machinery. Train farmers on spraying.
Heavy rain, hail		Shade, windbreaks	Need evidence on how widespread the problem of hail is.
Drought	Old trees may be more resilient because of deep roots. Clonals could be more susceptible	Increase ground cover/mulch Increase soil organic matter Irrigation	Need more field studies and experimentation to determine advantages and disadvantages of each possible tool
Drought	Gypsum soil treatment to drive roots lower		Micro-trials only to start – i.e. one or two trees.
Post-harvest: Water for washing	Penagos demucilators Water harvesting		
Subsistence crops: pests & diseases	Virus resistant varieties?	Push-pull technology for maize stem-borers	Training in GAP, composting, IPM etc.
Human health: malaria		Permethrin bed nets	Awareness raising, training for extensionists and farmers

Early warnings	More timely applications for events triggered by ENSO		For follow-up during hoped-for project with Reading Uni & Lorna Young Foundation

Table 2 . Classification of risk factors and a partial list of potential remedies (tools).

As can be seen from Table 2, the need for building capacity is great and this implies a major investment of time and funds on behalf of farmers and support institutes. It means that the farmer will have to take many more actions than previously and be prepared to outlay more funds in the hope of achieving a lower risk as s/he becomes more proactive and less reactive.

The question arises as to the farmer's willingness or ability to increase efforts to adapt, as well as our confidence in the efficacy of the measures recommended. Although there are always difficulties with recommendations, in a complex situation such as the present one, where uncertainties are high, it will be important to prioritise activities according to degree of confidence that they will work and farmers' abilities and willingness to implement.

7. Suggested actions

From the previous sections, we see many climate threats that together present a formidable challenge to anyone trying to deliver effective adaptation options. There are many actions and activities required and only a few of these can be attempted during the present project.

To a great extent therefore, the following list will have to be modified by local staff to achieve sufficient successes to warrant project expansion. Hence the following list of actions (Table 3) is approximate only.

Consultant will endeavour to backstop on development of trials and collection of further information as and when prioritised by local staff.

Action	Tool	Activities	Comments
Fact-finding and mapping of specific extreme climatic variables: i.e. especially prevalence of drought and high temperature symptoms during late-dry season and early wet season	Stress test	Preliminary data collection of low altitude coffee zones as well as any accounts of recent problems in order to locate and plan likely places to visit during next dry to wet season transition period (Oct-Nov) Intensive field-visits during transition period to collect	Careful collation of reports can help prepare for later data collection Measurements to include leaf-scorch, wilting, pest problems,

		data of effects of extreme weather on coffee plants	flower abortion, soil moisture, air and soil temperatures on hot days. Data collected would eventually help to zone coffee according to degree of problems
Further farm fact-finding	Local coffee information tool	Continue to collect and record experiences from farmers, especially CC innovations (successful or not) and other projects in the zone (on-going or finished) Ask about and locate any farmers who have abandoned coffee Record unusual events – e.g. hail storms, pest outbreaks, fires Consider use of field notebooks for farmers to record unusual events (e.g. fire, flower abortion, etc.) Install improvised rain gauges in observation plots. Investigate further utility of i-buttons as an alternative to expensive weather stations.	We can learn a lot from farmers' current attempts at adaption, even when not successful A lot can be learned from farmers who have given up – why? What was the final straw? Etc. A catalogue of extreme events which are then mapped could build into a valuable database Data collected would eventually help zone coffee according to degree of problems
Extreme weather history and future	Weather scenario tool	Evaluation of past coffee and climate data for Tz – e.g. to relate production fluctuations to weather events Projection of future weather patterns, especially occurrence of extreme temperature maxima – using weather generator	University of Reading MSc
Turning information into knowledge	Mapping tool	All field data should be mapped to reveal patterns and give all stakeholders, donors etc. a more visual	Local GPS expert to assist

		understanding of issues	
Ground cover experimentation a) Mulch	Soil moisture conservation tool	Mulching trial(s) Collect material (maize stover, etc.) at harvest time Treatments of various depths of mulch e.g. 5, 10, 15, 25 cm. Measure soil moisture vs control (no cover) to end of dry season. Also take temperature readings over and under mulch Measure rate of decay of mulch	If little is available near the trial plot, bring in from another source Weigh or calculate total volume and ask farmer how much cattle food it represents (for later cost/benefit analysis)
Ground cover experimentation b) Cover plants	Erosion protection/ Moisture conservation tool	Small-scale trials with weed selector Find, identify and test candidate ground cover plants Take over and under temperature and soil moisture measurements	Make or purchase weed selectors Test on small plots to evaluate efficacy and acceptability by farmers One or more species already collected and under trial – measure rate of growth, spread, survival of dry season and whether there is any effect on soil moisture retention by end of dry season. Compare against mulching on same site if feasible
Composting of coffee pulp and other residues (e.g. cattle dung)	Soil resilience tool	Composting experiments with various combinations of maize residues, pulp, dung and other materials as available How do farmers compost? Are they doing it well?	A wide range of possibilities and styles of composting are possible. In the first instance look for any successful local projects by NGOs Consult CFU
GAP – field diagnostic	Resilience assessment tool	Soil analysis – pH testing Plus full soil and leaf analysis if possible	pH testing is cheap and should be routine. Backed up with soil analysis of representative soil types to confirm TNS evaluations.

		Examine coffee leaves for deficiencies Establish fertility regime NPK +Zn + B? Examine trees for pest and diseases problems. Mark all trees with stem borer for eradication Two or three unproductive trees should be dug up for root examination. Dig a trench to examine root depth of old trees	TNS suggests Zn and B are very low in Mbeya, similar deficiencies were noted during field visits of this consultancy Do foliar spraying if possible. Keep samples of diseased roots for further examination. How deep do roots of old trees go? I.e. how resilient are they to drought?
Coffee tree replacement protocol	Resilience implementation tool	Unproductive trees should be replaced. An acceptable way of doing this should be discussed with farmers – what are the decision criteria? Stumping vs. clones vs. seedlings	The various problems of replacing old trees with deep roots for new trees with shallow roots in a time of weather extremes, needs to be confronted.
Shade	Temperature reduction tool Tree selection tool	Locate a range of farms where shade is used and study its effects, soil type, species present, how shade use changes with location and altitude. Concentrate more on low altitude coffee. Study during the dry season by measuring tree stress (see above). Which shade species are used and where?.	Shade is the only tool to lower maximum temps – if there is increasing flower abortion, shade will rapidly become a critical issue. Preliminary TaCRI data suggests poor results with shade. Likely competition for scarce soil moisture between coffee and shade. Follow up to find out more about these experiments. Project field plots with Grevillea saplings looked in poor condition. Shade tree saplings may themselves need temporary shade to get established.

		Collect farmers' and extensionists' experiences and preferences for trees according to a range of criteria. All above data should be plotted on maps. Field trials with candidate species would be separate project	
Review farmers' spray machinery	Assessment tool	Nozzles are a priority; test for efficiency of coverage with fluorescent dye and paper strips	Field observations suggest that coverage is very poor and can seriously compromise the efficiency of applied products and squander precious water Consult CFU
Collection of historical production data.	Knowledge tool	Yield data from Mbeya, Mbozi, Arusha, etc.	Disaggregated data from zones and districts can reveal true extent of year-to-year production fluctuations, especially when plotted against historical met data Very useful for retrospective met. study with Reading
Develop extensionists' field-notebook	Knowledge tool	Include some simple tables to fill out in order to better capture local experiences	E.g. record new weather events, road wash-aways etc. Record innovations (e.g. unusual, effective soil cover plants, water storage)
Develop extensionists' toolkit	Knowledge tool	Camera and GPS Tape measure Tow-rope & saw pH soil kit,	Encourage liberal use of camera to record new/unusual events. Train and encourage extensionists to routinely collect data (e.g. shade, cover plants, farmer innovations) to build into a potentially important GIS database
Subsistence crops	Resilience tool	Identify main production constraints – e.g. pests, diseases, weeds Carry out FFS type activities with candidate remedies for identified problems	IPM including push-pull technology for maize stem borers and striga. Consult CFU
Post-harvest treatment	Water sparing	Demucilator/ecopulper for	Water will always be a salient

	tool	reduced post-harvest usage	issue, at least one Penagos machine could be worth testing in a range of ways to evaluate cost-effectiveness. 'Clean water is an issue' said TaCRI's Isaac Mushi in Mbozi
Water 'basins'	Water harvesting tool	Basins under and next to trees to harvest rainwater	Trials already underway, continue to monitor
Water harvesting – ponds, pits, tanks: information gathering	Information tool	There are a wide range of techniques to collect excess wet-season rain and store it. These should be listed Develop potential list of organisations and consultants on this topic for future consultancy	There are many examples of water harvesting in Tz & E Africa, efforts should be made to identify where they are/were and visit them where possible.
Irrigation (micro)	Water management tool	Review information on any local/regional activities, especially low-cost small scale solutions. E.g. Plastic bottles with drip cones, porous sunken pots etc.	Normal irrigation is too costly for most farmers Some farmers might be willing to experiment with rustic drip devices in extremely dry areas?
Irrigation (macro)	Water management	Scoping assessment of irrigation needs and potential. Consultant to evaluate most likely options for main coffee regions – i.e. scope for irrigation from rivers, small dam construction, large scale water harvesting, with ball-park cost estimates	If the meteorological prognosis is gloomy and is corroborated by a growing database of field experiences such as poor wet season start, flower abortion, etc. then the need for large scale irrigation will become compelling.
Farmer & field agent health	Resilience	Malaria is likely to increase Monitor local health situation and take precautions as recommended – extensionists should be made aware of an changes in risks	As temperatures rise and prolonged high humid events take place, there will be more insect vectored disease outbreaks.
Early warning	Short range forecast	The aim is to provide short to seasonal advice to farmers of impending storms and ENSO events	Potential project activities with Reading University & Lorna Young Foundation if approved

Zoning	Planning tool	Develop the concept of different altitude zones for coffee, where recommendations would differ. By the end of the project, some agreement about the concept of zoning with approximate altitude ranges and number of categories should be established.	E.g. high altitude coffee could be more orientated to maximise production, whereas lowest would be oriented towards increasing resilience and diversification. It will be important in the future that extensionists are always aware which zone they are working in and the implications this has for recommendations.
Nursery techniques	Resilience	Experiments to improve root development prior to planting out. Large bag sizes, deeper sleeves, hydrogels etc. could be tried. Especially to trial alongside clonal transplants.	Increased planting rates of resistant coffee may be needed in the future which will have to survive during unexpectedly poor rainfall in the wet season.
Preliminary gypsum evaluation	Resilience	Micro scale trials on a range of soil types to establish primary effect on root depth	One or very few trees per treatment only. Liaise with HRNS Brazil for details.
Diversification	Resilience	Extensionists should collect data from any low-altitude coffee farmers abandoning coffee – what are they planting instead?	There will be an inevitable loss of farmers at lowest altitudes. Much can be learned about their experiences and decision-making criteria.
Arabica to Robusta	Resilience		Unlikely to work because of lack of water. Not a priority
Grafting			
Clone trials			
Mycorrhyzae		Look for any project activity with mycorrhyzae in Tz	Results from 6 years of trials in Colombia have given impressive results – to lower input costs CFU activity?

Table 3. Synopsis of actions that could be taken or initiated during present and future projects related to climate change.

The above tabulated list is a counsel of perfection that cannot be completed within the present project – local management will have to determine priorities according to resources available. However, most of the suggestions should be seriously considered and some, which at this stage require little more than information collecting and/or training, might be accomplished with relatively little effort.

8. Hypotheses and principles

It is useful to develop some basic hypotheses about how climate is and will affect coffee in the Mbeya zone, in order to orientate future work and project development. The following are some initial suggestions. These should be examined from time to time to see whether events and new knowledge are congruent with these hypotheses and whether specific activities are testing them. The list is preliminary and incomplete, new ones can be added as the team become more familiar with the topic.

H0 Tanzania has already undergone substantial climate change which means that farm resilience is already being severely tested. Inevitable continuing change will cause major transformations at the farm and landscape level and these could occur quite quickly.

It is to be hoped that this hypothesis is wrong – but project leaders should be alive to the possibility; ecosystems do not always change in an incremental, linear fashion and quickly spring back but instead flip to another state. Such change may manifest itself in arrival of new pests and diseases, tree and crop death, drying up of previously reliable water sources, widespread fire, etc.

H1 Temperatures are rising with more hot days exceeding 30°C and reaching 34°C in the lowest coffee zones, which will cause increasingly widespread flower abortion.

The relationship between high temperature, drought-stressed trees, soil type and coffee variety is not well quantified. However prolonged temperatures above 30°C are bad for Arabica and intensive field observations and measurements around the flowering period can help to more accurately define potentially dangerous situations.

H2 Low annual rainfall with intense and long dry seasons means that much of the lower coffee lands of Mbeya are now marginal with only a limited future.

Most affected areas will be subject to low yields, poor quality and increased pest/disease attacks. The validity of this hypothesis should be tested by making sure that some observation and plots are directed towards the lowest altitude coffee. Data to support this should eventually come also through field-notebook data.

H3 Simple ways to retain/improve soil moisture for coffee and food crops are the most likely to yield quick and useful results.

The widest possible range of tools should be trialled on a small scale in order to select a few candidates for more extensive trials. This would include a range of possible soil covers, a weed selector trial and rustic drip technology.

H4 Early warning advisories from national and international meteorological institutes are sufficiently useful to be the basis of warnings and updates to farmers.

Information about approaching storms and ENSO events are accurate enough to be useful to farmers. Hopefully this can be explored more fully through the Reading University connection.

H5 Without irrigation, shade is not an important tool to combat various aspects of climate extremes.

Soil moisture deficits are too extreme in many situations to support both coffee and shade, because although shade reduces evapotranspiration of coffee, overall moisture loss per hectare increases with added shade trees. The team should attempt to disprove this hypothesis by finding un-irrigated shaded coffee at low altitude that is protecting coffee and providing reasonable yields.

H6 New clonal varieties have poor root systems and therefore will not fare well in extreme drought conditions.

This may well not be true and can be tested through field trials.

H7 There are locally sourced ground-cover species that can act as effective controllers of soil erosion.

General ground cover is poor in coffee plots but there are locally growing plants that can survive such conditions and that are acceptable to farmers. Field workers should be looking out for candidate species and be prepared to trial them, possibly in conjunction with the weed selector.

H8 There is a minimum profitable altitude for growing coffee without irrigation, which is approximately 1350 m.

This figure is a guess based on an extrapolation of Tmax data from the Mbeya station which would suggest that flowering-period temperatures around 1350 m could exceed 33C. Data from future field observations and field notebooks can help to test this hypothesis.

H9 There are farmers in the zone 1200 – 1400 m that used to grow coffee but have given up.

Again this is a guess which could be tested by field surveys. Their experiences would be useful to guide other farmers in the future.

H10 Farmers in the Mbeya zone are poorly buffered against further climate change. They will have increasing difficulties in the future, the lower limit of coffee growing will rapidly rise and diversification will become an increasing issue.

Many Mbeya coffee farmers face severe climate-related challenges, due to a particularly deadly combination of long intense dry season, high maximum temperatures and scarce irrigation facilities. The most successful tools will be those that they can use for more than just coffee – i.e. mostly soil management and water collecting and sparing activities. Farmers will start to grow more arid zone crops.

H11 There are many useful farmers' experiences and innovations waiting to be collected that can help to devise new trials and tools or variants of tools.

Field workers should be encouraged to collect farmer innovations and experiences, both successes and failures.

H12 increasing temperatures mean that CBD will become less common and CLR more common.
CBD is a cool temperature disease; CLR is a warm temperature disease. Short wet seasons may well limit the spread of both diseases. Field notebook data should eventually show whether this is true.

9. Overview
In Mbeya is seen the most extreme and marginal conditions for coffee growing in the Coffee & Climate project to date. Principal concerns are:

- very long and intense dry season with sometimes an intermittent start to the wet season
- very low annual rainfall
- very high maximum temperatures are likely around the time of flowering. At Mbeya meteorological station the maximum recorded temperature is 31°C at a height of 1701 m above sea level. This has been recorded in November, just at the time of flowering after the first rains.

Since coffee is found as low as 1350 m and possibly lower, it would seem that temperatures of 33°C are possible. Farmers at these altitudes have reported flower abortion.

The only adaptation tool to guard against high temperatures is shade. But here a second problem arises: the dry season is very intense, with little rain for four or more months. Shade deep enough to protect coffee from extreme temperatures might also tend to compete for scarce soil moisture with coffee and would certainly also reduce flowering and hence yields.

The inevitable conclusion is that increased water harvesting and irrigation is required over much of the region. The costs for supplying such solutions will be high, but work needs to start to scope out feasibility.

These problems are likely to increase over the coming years. It is likely that coffee farming will become more risky and less profitable. Difficult decisions will have to be made about who to prioritise for adaptation and who to consign more towards diversification.

The extremes of weather may well bring unexpected outbreaks of pests and diseases that may demand emergency responses – e.g. *Spodoptera exempta* currently causing problems in Zambia.

The combination of extreme weather and extreme poverty are a particularly problematic mix. There are no simple solutions. The approach recommended here is to accept the inherent complexity and adopt a modern pragmatic approach to dealing with it. This involves:

- Probing – the widest possible range of tool testing on a small trial basis, expecting a high failure rate;
- Selection – review initial results of trials, select promising options;

- Amplify – re-test selected options on a bigger and more detailed scale.

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Appendix 1.

Extract from: The Economics of Climate Change in the United Republic of Tanzania. Global Climate Adaptation Partnership, pp 139 (2011).

Case study of soil and water conservation (SWC) measures in the Western Pare Mountains, Tanzania

The Western Pare Mountains are located within the semi-humid areas stretching south-eastwards. The area has a very long SWC history dating back to the pre-colonial period; it was one of the nine districts targeted by the government for SWC works since the 1930's; and represents other highland areas in terms of farming system, soil degradation problems and upstream - downstream water use relationship. Agriculture is the major economic activity in the area. Agricultural production in this zone is only possible through rainwater harvesting (RWH) using supplementary water mainly from ephemeral flows during the rainy season. Soil and water conservation measures are needed to control soil erosion and sustain agricultural production on steep slopes of the mountains. Important SWC measures include stone terraces, bench terraces, contour terraces, fanya juu and grass strips.

The investment costs necessary to establish the SWC measures include labour, equipment and materials, and maintenance. Benefits include all gains in current and future production as a result of implementing the respective SWC measure. This includes effects of SWC measures on retention of soil nutrient and water reflected in an increased crop yields and other outputs, such as fodder for livestock.

Evaluation of the efficiency of bench terraces, *fanya juu* and grass strips done by Tenge, et al (2007) in the

Western Usambara Mountains, which are not far apart with the Western Pare Mountains, showed that all the three SWC measures were effective in retaining soil moisture and reducing soil loss compared to the without conservation situation. Bench terraces were more effective by retaining more moisture than *fanya juu* and grass strips. The fields with SWC measures also produced a significant increase in maize and beans yield in comparison to the without conservation situation.

Bench terraces were found to be more costly to establish than fanya juu and grass strips, but with highest financial returns in the long run. For the establishment of bench terraces a total of US$ 215 ha-1 was required compared to US$ 165 ha-1 and US$ 84 ha-1 for fanya juu and grass strips, respectively. However, even after overcoming the initial investment costs, the cash flow from grass strips was still lower than the other two SWC measures. Bench terraces had the best internal rate of return (19%) followed by fanya juu (14%) and grass strips (6%). These results suggest that, farmers who are able to invest in bench terraces, will be able to recover their investment faster than from the fanya juu and grass strips.

Case study of Mwega smallholder irrigation project

Mwega smallholder irrigation project is located in Kilosa district, Morogoro region. The construction work commenced on November 17, 2000 and was completed in March 2002. It covers about 580 hectares cultivated by 740 households benefiting approximately 7000 people from Malolo A and B, Mgogozi and Nyinga villages.

Main crops grown are paddy and maize during rainy season and onions, cabbage, potatoes, and pulse during dry season. The main objectives of the project were to increase productive capacity, improve both household food security and income of farmers; and hence alleviate poverty. The project involved construction of Mwega headwork, irrigation canals works, road improvement and river improvement works.

The project cost translates to USD 15,700/ha, which is expensive compared to many smallholder irrigation schemes in Tanzania. The cost for developing a 400 ha Magoza village irrigation scheme (located in Mkuranga, Pwani region), for example, is estimated at about USD 2,470/ha. In most of the irrigation projects beneficiaries do usually contribute cash or labour. For example, in the Magoza scheme farmers are expected to contribute their labour (bush clearance of farm service roads route and canals, spreading of soil material on the service road, and excavation of drainage canals) estimated at about USD 135,000.

After the rehabilitation of the irrigation infrastructures, scheme management, including Operation and

Maintenance (O&M) activities, was subsequently entrusted to farmers under the auspicious of Mwega

Irrigation Primary Cooperative Society called “CHAUMWE”.

The main channels are cleaned by community based labour, locally known as ''Msalagambo''. Farmers clean secondary and distribution channels from which they get water for irrigation.

As a result of the rehabilitation of the scheme, tenants in Mwega benefited from a more reliable supply of water to their fields. Consequently, food security, household income and employment opportunities to the nearby communities have been improved significantly. Paddy production has increased from 2 t/ha in 2005 to 5.0 t/ha in 2008. Other benefits include increase in the value of land through an increase in rental prices, improvement in water use efficiency, improved farming practices, and reinforcement of farmers organization. The improvements have been largely contributed by the trainings provided by Kilimanjaro Agricultural Training Centre (KATC) on paddy rice agronomy. More than doubling rice yield per ha reduces the need to expand the cultivated area consequently reducing GHGs emissions and particularly of methane.

Appendix 2. Example of farm questionnaire.

Date		Location	District			PO	
			Village			GPS village	
			Soil type			Altitude	

Farmer	Name	
	Age	

Details	Farm size (ha)	
	Main coffee var.	
	Tree density (apprx)	

Plot	1st	2nd	3rd
Yr started			
Size (ha)			
Coffee			
Intercrop			

tick boxes

Problems	Climate	Pest	Disease	Finance	Labour	Irrigation	Other	synopsis of comments by farmer
Principal current problem								
Second problem								
Third problem								

Food crops	Yes/no			
Do you grow your own food?		If so, how much of your basic requirements are covered?		%
		How much time a week is spent on food production?		hrs

	synopsis of comments by farmer
What changes have you noted in coffee farming since you started (any aspect, env., social, economic)	
Future: do you intend to keep growing coffee?	

Visual (state of farm from 5 min walk)

tick boxes — brief observations (use key words)

Coffee health	Poor	So-so	Good	Excellent	

Shade or intercrop	None	Light	Medium	Heavy	

Intercrop health	Poor	So-so	Good	Excellent	

Plot has a well?	Yes	No	

Erosion	None	Little	Medium	Heavy	

Global impression of farm [1 = very bad to 10 = exceptional]

Farmer innovation

Other comments (be brief)

Appendix 3 Specific Tools

Outlined below are a range of possible tools to be developed and tested by local staff. They are invited to take these as starting points and develop them accordingly. Ideally certain tools could be championed by nominated individuals who are made responsible for collecting further information and planning activities; effectively they would be invited to take ownership for one or more tools. Tools are a principal output of the project and hence each one should be turned into a dossier of information with clear accounts of activities to test them in the field.

Tool: Good Agricultural Practice

Coffee variety: Arabica

Climatic hazard: drought, higher maximum temperature

Type: adaptation on-farm

Purpose: drought resistance, erosion, soil management, soil moisture, water runoff, disease

Concept: farmer to adopt a series of measures to cope with increased stresses caused by more extreme weather.

Drawbacks: extra labour and benefits may not be quickly realized

Costs: to be estimated

Activities: starts with pH test and soil/leaf analysis if available to determine nutrient requirements for the following season.

If no soil-test available: observe leaves for mineral deficiencies and select treatment accordingly.

For first year, do trial rows or small number of trees with a) farmers usual treatment, b) treatment (e.g. liming, micronutrients) to evaluate results together. If it doesn't work/farmer not satisfied, then try another treatment. Small scale means this is a low-regret strategy.

Feasibility: high

Applicability: to be carried out in all areas

Effectiveness: high

Other comments: collect small samples of fertilizers used by farmers, including those they suspect as being fakes, for subsequent chemical analysis

Tool: deciding on replanting vs. stumping

Coffee variety: Arabica

Climatic hazard: drought

Type: assessment

Purpose: drought resistance

Concept: farmers may be wary of pulling up old trees and doing so could be a maladaptation since old trees have deep roots, hence replanting in extreme conditions might have a high failure rate. A way is therefore needed to help decide on advisability of replanting vs. stumping of an existing variety which may be less productive but more resilient to drought because it will have well-established roots.

Drawbacks: none identified

Costs: to be estimated

Activity: small replanting trials, comparing stumping with new variety, which could be seedling and/or clonal material. Carry out regular joint examination of growth and subsequent fruiting together with farmers; record their opinions and eventual conclusions.

Feasibility: high

Applicability: low altitudes especially

Effectiveness: high

Tool: stress evaluation

Coffee variety: Arabica

Climatic hazard: drought, higher maximum temperature

Type: assessment

Purpose: drought resistance, soil moisture, disease

Concept: the dry season is intense in Mbeya and the transition to the wet season can be difficult due to intermittent rains and high maximum temperatures, leading to flower abortion.

There is a lack of measurement and observation of this transition period, and how it varies between localities and altitudes. A better understanding of how trees respond to extremes will help to design appropriate adaptation tools.

Drawbacks: none identified

Costs: to be estimated

Activity: establish a scale of stress by observing, counting and photographing leaf wilt, leaf scorch, leaf drop, flower abortion; also measure soil humidity levels and maximum ambient temperatures during visits.

Carry out from early to mid-dry season until wet season is well under way, so that stress can be followed right the way through and related to soil moisture and temperature.

If possible, conduct some more detailed studies: is level of stress related to subsequent performance over the next season? This could be tested by marking some trees and making longer term evaluations.

Feasibility: high

Applicability: universal

Effectiveness: to be determined

Tool: shade information collection

Coffee variety: Arabica

Climatic hazard: higher maximum temperature

Type: assessment

Purpose: heat stress

Concept: because of very high maximum temperatures, shade will be increasingly needed. There is no time to develop shade trials, so all information will have to be collected *in situ*, from existing farms.

Drawbacks: none identified

Costs: to be estimated

Activity: find a range of examples of farm plots with shade, at a wide range of altitudes. Record species, spacing, shade density (approximate: e.g. light, medium, heavy). Take plenty of photos. Record temperatures in shade and full sun.

Observe state of coffee, especially towards end of dry season. It is hoped to find coffee plots with heavy shade which significantly protect the coffee from high temperatures without materially affecting yields.

From this, develop a database of shade trees and localities and formulate a hypothesis about which are the best shade trees to use for future trials.

Feasibility: high

Applicability: universal

Effectiveness: to be determined

Tool: information management

Coffee variety: Arabica

Climatic hazard: all

Type: assessment

Purpose: knowledge management, decision making

Concept: a wide range of information is available but is not collated and presented in easily understandable formats

Drawbacks: none identified

Costs: to be estimated

Activity: collect together all field data and supply GPS data where missing. Create map(s) of a wide range of possible variables, including project farms locations, pest and disease reports, soil problems, yields, other measurements, e.g. results of proposed stress tests, shade plots, etc., as well as any other unusual/extreme reported events, e.g. flood and fire.

It is hoped that such data could be overlaid onto maps with altitude and/or temperature to reveal patterns and relationships emerging from the data.

Feasibility: high

Applicability: universal

Effectiveness: to be confirmed

Tool: Ground-cover plants

Coffee variety: Arabica

Climatic hazard: higher maximum temperature, drought, rain: short term rain events, prolonged rain, intermittent rain

Type: adaptation on-farm

Purpose: drought resistance, erosion, heat stress, irrigation, soil management, soil moisture, water holding, water management, water runoff

Concept: low growing non-aggressive plants form a complete cover of soil and reduce soil erosion, because roots of the cover crop anchor the soil, improve soil structure and slowing action on running water. A good cover will also reduce the need for weed control activities.

Drawbacks: none foreseen

Costs: to be estimated

Activity: assay locally procured species under a range of conditions and evaluate speed of growth, ability to compete against other weeds and farmer satisfaction.

Feasibility: high

Applicability: universal

Effectiveness: to be determined

Tool: Mulch

Coffee variety: Arabica

Climatic hazard: higher maximum temperature, drought, rain: short term rain events, prolonged rain, intermittent rain

Type: adaptation on-farm

Purpose: drought resistance, erosion, heat stress, irrigation, soil management, soil moisture, water holding, water management, water runoff

Concept: cover bare ground with a protecting layer of cut vegetation, including cut weeds, corn stover etc.

Drawbacks: fire, termite damage, reduces available food for livestock

Costs: to be estimated

Activity: experiment on different thicknesses of available material, evaluate effectiveness in retaining soil moisture and reduction of temperature underneath as the dry season intensifies, in comparison to uncovered ground. Relate results to costs and level of farmer satisfaction.

Feasibility: high

Applicability: universal

Effectiveness: to be determined

Tool: Weed-wipe

Coffee variety: Arabica

Climatic hazard: higher maximum temperature, drought, rain: short term rain events, prolonged rain, intermittent rain

Type: adaptation on-farm

Purpose: drought resistance, erosion, heat stress, irrigation, soil management, soil moisture, water holding, water management, water runoff

Concept: using a weed-wipe can reduce weed competition and encourage a carpet of low-growing plants that will anchor the soil, hence reducing soil erosion and assisting with efficient micro-water harvesting within the plot.

Drawbacks: plants selected through use of the weed-wipe may not reduce soil moisture, hence in this respect may be inferior to mulch; not an 'organic' procedure

Costs: to be estimated

Activity: carry out trials with the weed-wipe, starting before end of wet season. Through regular visits record (with photos) the effectiveness of this procedure in establishing a carpet of natural and spontaneously emerging plants.

Feasibility: high

Applicability: universal

Effectiveness: not known

Tool: Early warning service

Coffee variety: Arabica

Climatic hazard: short term extreme rain events, prolonged rain or drought (ENSO)

Type: assessment

Purpose: early warning

Concept: prior warning of major weather events (mainly by radio and mobile phone) can help farmers take avoiding action and re-plan farm activities such as fertilizer application

Drawbacks: inaccurate forecasts may reduce credibility

Activity: joint activity with Reading University and Lorna Young Foundation; pending further information on funding

Costs: to be estimated

Feasibility: high

Applicability: universal

Effectiveness: not known

Tool: improving growth of coffee seedlings/clones in nurseries

Coffee variety: Arabica

Climatic hazard: higher maximum temperature, drought, intermittent rain

Type: adaptation on-farm

Purpose: drought resistance, heat stress, water holding

Concept: replanting coffee may become increasingly important if farmers are to keep up with latest varietal improvements and as well maintain plots at peak performance. At the same time, planting out may become more problematic if this coincides with extreme weather events. Good root structure gives the coffee seedling/clone the best chance of quick and strong growth.

Drawbacks: none foreseen

Activity: set up small-scale trials with coffee seedlings and clones with a) different sized poly sleeves; b) hydrogels; c) mycorrhizae (if available or easily importable); d) combinations of these.

Costs: to be estimated

Feasibility: high

Applicability: universal

Effectiveness: to be determined

Tool: gypsum micro-trial

Coffee variety: Arabica

Climatic hazard: drought

Type: adaptation on-farm

Purpose: drought resistance

Concept: in Brazil gypsum has been shown to cause deeper root growth by opening soil structure and pushing nutrients to deeper layers in the soil. Roots grow down to follow the nutrients. Deeper roots provide resilience to drought.

Drawbacks: few if done at very small scale. Unlikely to work on sandy, open-structure soils.

Activity: small-scale tests to evaluate whether the technique to improve root depth works with Mbeya soils and hence improve resilience to drought**.** Carry out very small trials (e.g. one to three trees per treatment), in diverse locations – e.g. on farms on any unused scrap of land, with young recently planted out coffee trees. Carry out soil test first, then apply gypsum (one or more doses) take occasional measurements of tree health and growth to compare with controls. Examine root structure through excavation after 9 to 12 months.

This experiment can be done on other tree types as well – it could feasibly be a technique to help anchor shade trees on erosion-prone soils.

Feasibility: moderate

Applicability: potentially universal

Effectiveness: potentially high on the right soil