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Smallholder Banana Farming Systems and Climate Variability: Understanding the Impacts, Adaptation and Mitigation in Mpigi District, Uganda

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Dedication

I dedicate this thesis to my family, particularly to my beloved wife Barbra Birungi Zake and daughter Jasher Ashley Nakibengo Tezzikyabbiri.

Declaration

I declare that the thesis is an original work and no material in this thesis has previously been submitted at this or any other universities.

Acknowledgement

To God the Almighty thank you very much for bringing me this far in my academic and professional development.

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Abstract

Overall the study contributes to sustainable banana farming systems for food security under the prevailing climate conditions. Data were collected through semi-structured interviews and focus group discussions involving selected farmers. They were analysed using the SPSS 16 to generate descriptive statistics. Soil samples were obtained randomly from two layers in 20 farms identified through simple stratified sampling. They were analyzed for total soil organic matter, total soil organic C, pH, total N, plant-available P, exchangeable K, soil texture and bulk density. Organic C stocks were calculated based on soil organic C and bulky density. Aboveground plant biomass was determined using allometric equations based on tree diameter and height. Belowground biomass was calculated using equations based on the respective aboveground plant biomass.

The study revealed that farmers consider implementation of climate change disaster preparedness strategies as inadequate. This triggered implementation of early actions by farmers to respond to climate change disasters. Climate change impacts triggered adaptation and mitigation innovation´s development by farmers. The banana-coffee agroforestry system had significantly higher total soil organic matter, and total N compared to the banana monoculture. Similar trends were observed for soil organic C and total C pools. The former contained 1.5 times more soil organic C. However, the reverse was true for exchangeable K.

It´s concluded that:

a. Farmers consider implementation of climate change disaster preparedness strategies at community level as inadequate;

b. Climate change impacts trigger farmers to develop innovations for adaptation and mitigation;

c. Banana-coffee agroforestry improves soil fertility and C storage compared to banana monoculture farming systems under the current climate conditions.

Key words: *Climate Change, Adaptation, Mitigation, Tropical Agriculture, Soil Carbon, Lake Victoria Basin*

Zusammenfassung

Die vorliegende Dissertation leistet einen Beitrag zum nachhaltigen Anbau von Bananen unter den Aspekten Ernährungssicherheit und Klimawandel. Die Datensammlung erfolgte durch semi-strukturierte Interviews und Zielgruppendiskussionen mit ausgewählten Landwirten. Die Daten wurden mit SPSS 16 statistisch ausgewertet. Bodenproben wurden auf der Basis geschichteter Zufallsstichproben aus zwei Horizonten in 20 landwirtschaftlichen Betrieben entnommen. Sie wurden auf organische Bodensubstanz, gesamt-organisches C im Boden, pH, Gesamt-N, pflanzenverfügbares P, austauschbares K, Bodentextur und Lagerungsdichte analysiert. Organische C-Vorräte wurden auf Basis von organischem C im Boden und Lagerungsdichten berechnet. Oberirdische Pflanzenmasse wurde mit allometrischen Gleichungen basierend auf Durchmesser und Höhe der Bäume bestimmt. Unterirdische Biomasse wurde auf Grundlage der jeweiligen oberirdischen Pflanzenmasse berechnet.

Die Studie ergab, dass Landwirte die Umsetzung der Strategien zur Katastrophenvorsorge als unzureichend betrachten. Dies veranlasste Landwirte dazu, mit frühzeitigen Maßnahmen auf Klimawandel-bedingte Katastrophen zu reagieren und Innovationen zur Anpassung und Abmilderung zu entwickeln.

Systeme mit Bananen-Kaffee-Agroforstwirtschaft hatten einen signifikant höheren Anteil organischer Bodensubstanz und Gesamt-N als Bananen-Monokulturen. Ähnliche Trends wurden bei organischem C im Boden und Gesamt-C-Pools beobachtet. Erstere Systeme enthielten 1,5-mal mehr organisches C im Boden. Jedoch war bei austauschbarem K das Gegenteil der Fall.

Die Studie kommt zum Schluss, dass:

a. Landwirte die Umsetzung der Strategien zur Katastrophenvorsorge und zum Klimawandel auf Gemeinschaftsebene als unzureichend betrachten;

b. Auswirkungen des Klimawandels Landwirte dazu veranlassen, Innovationen zur Anpassung und Abmilderung zu entwickeln;

c. Bananen-Kaffee-Agroforstsysteme die Bodenfruchtbarkeit und C-Speicherung im Vergleich zu Bananen-Monokulturen verbessern.

Schlagworte: *Klimawandel, Anpassung, Innovation, Abmilderung, Tropische Landwirtschaft, Bodenkohlenstoff, Victoriasee-Becken*

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Abbreviations and Acronyms

AGB	Aboveground tree biomass
APPEAR	Austrian Partnership Programme in Higher Education & Research for Development
AGB	Aboveground biomass
BCA	Banana-coffee agroforestry
BGC	Belowground carbon
BGB	Belowground biomass
BM	Banana Monoculture
BOKU	University of Natural Resources and Life Sciences, Vienna
CBO	Community Based Organization
CDR	Centre for Development Research
CIGI	Center for International Governance
COP	Conference of Parties
CSO	Civil Society Organizations
DFID	Department for International Development
DSIP	Agricultural Sector Development Strategy and Investment Plan
EMU	External Monitoring Unit
ENR	Environment and Natural Resources
FAO	Food and Agriculture Organization
FGD	Focus Group Discussions
GDP	Gross Domestic Product
IPCC	Inter-Government Panel on Climate Change
IUCN	International Union for Conservation of Nature
LDCs	Least Development Countries
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
NAPA	National Adaptation Program of Action on Climate Change in Uganda
NEMA	National Environment Management Authority
NDP	National Development Plan
NGO	Non-governmental Organization
PEAP	Poverty Eradication Action Plan
RUFORUM	Regional Universities Forum for Capacity Building in Agriculture
SPSS	Statistical Package for Social Sciences
UBOS	Uganda Bureau of Statistics
UNFCCC	United Nations Framework Convention on Climate Change

Thesis structure

This thesis comprises of four parts. Part I presents the background to the research and development challenges; the research challenges and objectives of the study. In part II, the conceptual framework, research design and the methodological approaches are presented. Part III comprises the research papers:

- Zake, J. and Hauser, M. (2014a). Farmers' perceptions of implementation of climate variability disaster preparedness strategies in Central Uganda. Published in the *Journal of Environmental Hazards*. doi:10.1080/17477891.2014.910491.

  This paper is referred to as [Zake and Hauser (2014a)] throughout the thesis.

- Zake, J., Pietsch, S. A., Friedel J. K., Zechmeister-Boltenstern, S. (2015). Can Agroforestry Improve Soil Fertility and Carbon Storage in Smallholder Banana Farming Systems? Published in the *Journal of Plant Nutrition and Soil Science.* doi: 10.1002/jpln.201400281.

  This paper is referred to as [Zake et al. (2015)] throughout the thesis.

- Zake, J (2014b). Climate Variability triggers Innovations for Adaptation and Mitigation; A case for Smallholder Banana Farmers in Central Uganda. An unpublished manuscript submitted to the *Journal of Climate and Development* for consideration and is currently under review.

  This paper is referred to as [Zake (2014b)] throughout the thesis.

Part IV presents the general discussions, conclusions and recommendations from the study.

Part I

1.0 General background of the research and development challenges

1.1 Introduction

Climate change has serious implications on social, economic development on the entire global ecosystems. Indeed it threatens to reverse many years of development efforts, to frustrate poverty reduction programs in developing countries and overall global development targets (Stern 2006). The poorest countries would be most affected, with reductions in crop yields in most tropical and sub-tropical regions due to decreased water availability, and new or changed insect pest incidence (IPCC 2001a). The IPCC report further noted that in Africa and Latin America yields for several crops are likely to fall sharply with even small changes in climate because these crops are rain-fed and close to their maximum temperature tolerance. A fall in agricultural productivity of up to 30% over the 21st century is projected (IPCC 2001a).

This has great implications for sub-Saharan African agriculture and livelihood considering that agriculture is still a major contributor to economic growth and development of these countries. For instance, according to the World Bank (2009) agriculture provides about 65% for labor force; 45% of developing world's population lives in households involved in agriculture, while 27% households depend on agriculture for their livelihoods. Given the current climate change and variability, in future the gross domestic product (GDP) contribution by agriculture could reduce from 21% to as little as 4% by 2100 (Mendelsohn et al. 2000).

The IPCC (2007) argued that climate change is projected to have significant impacts on conditions affecting agriculture, including: temperature, carbon dioxide, glacial run-off, rainfall and the interaction of these elements. Thus, it also provided evidence to show that agriculture has significant effects on climate change, primarily through release of greenhouse gases such as carbondioxide, methane and nitrous oxide. The report further emphasized that the overall effect of climate change on agriculture will depend on these effects. Thus, agriculture contributes greatly to increasing CH_4 and N_2O concentrations. At a global scale, agricultural production contributes 14% and of this 38% of N_2O is from soil management; 32% of CH_4 is from enteric fermentation; 12% from biomass burning; 11% from rice production; and 7% from manure management (IPCC 2007).

Despite this, agricultural production provides opportunities as a solution for contribution to climate change mitigation depending on the management practices (FAO 2010b and World Bank 2013). Some management practices advance soil organic matter and carbon storage in the soil. They include: agroforestry (Nair et al. 2009); no tillage or avoided tillage, good management of residues, fixing nitrogen through biological processes (Savage 2011 and Starritt 2010) and organic farming practices (IFOAM 2009). However, in Uganda there is limited information about carbon storage and soil fertility of smallholder agroforestry farming systems and associated practices under the current and projected climate change and variability (Zake et al. 2015).

Climate change and variability will have grave implications on the Uganda agricultural sector considering that agricultural production is almost dependent on rainfall except for the horticultural sub sector (UBOS 2007). The NAPA (2007) observed that the impacts of climate change disasters such as prolonged droughts, floods and unreliable rainfall patterns are already evident in Uganda. Some of the implications as reported by Zake and Kaggwa (2007) and Zake et al. (2010) include: reduction in crop yields due to prolonged droughts; the unreliable rainfall patterns could leave several millions without food. Furthermore, droughts lower the country's productive capacity; reducing agricultural exports, increasing food prices leading to food shortages, nutritional deficiencies and an unstable macro economy.

Uganda is ranked as one of the most unprepared and vulnerable countries in the world in respect to climate change impacts (CIGI 2007). Uganda´s smallholder farmers who are the main base for agricultural production are even more vulnerable to climate change impacts and variability (Morton 2007). The presence of several policies and programs does not provide an effective safety net for smallholder farmers against climate risks. This is as a result of inadequate policy implementation due to limited resources allocation and logistics to support effective service delivery at different levels (UNDAC 2008 and NDP 2010). Some of the key policies and programs in this respect are: NAPA (2007); National Policy on Disaster Preparedness and Management (2010); NDP (2010); National Climate Change Policy for Uganda (2013); DSIP (2010); and the National Agricultural Policy for Uganda (2011).

Despite this, it's possible that smallholder farming communities try out various actions and innovations to live with these climate change impacts and variability (Adger et al. 2003). However, most of these are not known because they are not evaluated and documented. As a result they rarely inform the policy discourse with respect to community climate change adaptation and mitigation. Furthermore, some of these adaption strategies need further development and improvement (NAPA 2007). The community adaptation capacity to climate change impacts needs further strengthening considering that the climate change impacts are more persistent and extensive (Adger et al. 2003; Rao et al. 2007).

This study therefore, undertakes an in-depth understanding of the impacts of climate change on selected smallholder banana farming systems in Central Uganda. It focuses on the following aspects: smallholder farmers' perceptions of the implementation of climate change disaster preparedness policy strategies; smallholder banana farmers' innovations for climate change adaptation and mitigation; and resilience of smallholder banana farming systems under the prevailing climate variability.

1.2 Agriculture sector in Uganda; a general over view

Importance of the Agricultural sector

Mendelsohn et al. (2000) argued that the agriculture sector is a major contributor to the current economy of most African Countries, averaging 21% and ranging from 10 to 70% of the Gross Domestic Product (GDP). However, optimistic forecast of future development, depict that agriculture's share of GDP could shrink to as little as 4% by 2100 (Mendelsohn et al. 2000). Similarly, in Uganda, agriculture is the most important sector to the economy. This is because it provides the largest portion of employment opportunities, 66% in 2010 (UBOS 2011). In 2010/11, the sector accounted for 22.5% of total GDP. Agriculture accounted for 46% of total exports in 2010 (UBOS 2011). Uganda's economy largely depends on agriculture based on several crops and fisheries characterized by a high level of subsistence fishing and farming (UBOS 2011). Most of the agricultural production is done by smallholder farmers. Thus, 4.2 million agricultural households are involved (UBOS 2007).

Despite the importance of the sector to economic development, its performance in the recent years was poor. Hence, the real growth rate in agricultural output declined from 7.9% in 2000/01 to 0.1% in 2006/07 (UBOS 2008). Some of the constraints for sector performance as pointed out in the NDP, (2010/11-2014/15) included: Weak policy implementation especially the Plan for Modernization of Agriculture and the National Agricultural Advisory Services; High risk and cost of investment; High cost and limited availability of improved inputs; Limited human resources capacity; Weak institutions and structures; Poor management of natural resources; Inadequate meteorological services; and Limited extension support.

Average farm size

Uganda has a total area of 241500 km^2; of which, 236 000 km^2 is land cover and 44205 km^2 is under water (UBOS 2006b). By 2005, the land cover under cultivation had increased to about 99,018 km^2 (NFA 2007). Agriculture in Uganda is practiced by 4.2 million households with an average size of agricultural holding of 1.3 ha (UBOS 2007). About 37% of the arable land is under subsistence agriculture (UBOS 2008).

Major crops – food and cash crops

Uganda's main food crops include: banana, cassava (*Manihot esculenta*), sweet potatoes (*Ipomoea batatas*), millet (*Panicum miliaceum*), sorghum (*Sorghum bicolor)*, maize (*Zea mays*), beans (*Phaseolus vulgaris*), and groundnuts (*Arachis hypogaea*). Reports by Abele et al. (2007) indicated that bananas are one of the most important food and cash crops in Uganda, contributing 16 to 31% of total calorie intake. Other important food crops include cassava, sweet potatoes, millet, sorghum, maize, beans, and groundnuts. The major traditional cash crops are coffee, cotton (*Gossypium hirsutum*), tea (*Camellia sinensis*), and tobacco (*Nicotiana tabacum*), although over time in some regions of the country some food crops are also sold by smallholder farmers as cash crops (for instance bananas, maize) to meet household demands (Byrnes 1990). Central Uganda was traditionally the banana growing area in Uganda. However, to date bananas are increasingly grown in other parts of the country including Eastern and Southwestern Uganda (Tushemereirwe et al. 2001).

Uganda is the largest banana producer and 2nd largest coffee producer in Africa. Based on FAO, (2010a) reports, Uganda was the 11th largest coffee producer in the world and the 2nd largest banana producer in 2008. The same report noted that the estimated area under coffee and banana in Uganda was 265,000 and 1,815,000 ha, respectively in 2008.

Banana and coffee are predominantly grown as monocultures. According to Asten et al. (2011), both crops can be intercropped and this is a common practice in densely populated areas. These crops are equally important in Uganda and surrounding East African highland areas in Rwanda, Burundi, northwest Tanzania, west Kenya, and east Democratic Republic of Congo (Asten et al. 2011).

The trends of agricultural productivity for various crops are different. There is reported increase in the productivity of some crops especially millet, cassava and sweat potatoes (EMU 2007). On the other hand, productivity of maize, cotton, coffee and bananas has declined in recent years for different reasons including: changes in climate patterns (especially drought); crop pests and diseases; and poor soils management (EMU 2007).

Fertilizer use

With a population growth rate of 3.2%, the population current population of Uganda is 34.9 (UBOS 2014). This burgeoning population growth exerts more demand for food, fibre and fuel for the country´s natural resources (i.e. land and soils, forests, lakes and rivers) (State of Uganda Population Report 2012). In this respect, DSIP, (2010) denotes that a country that was once known for high levels of soil fertility is facing degradation of its land resources, top soil losses of as much as 5 tons ha^{-1} being reported in some areas. Implementation of robust sustainable agriculture, environment and natural resources management strategies is the only plausible strategy for addressing the natural resources degradation while addressing the demands for food, fibre and fuel by the population (State of Uganda Population Report 2012). For instance, the application of fertilizers through the integrated soil and nutrient management approaches are plausible technological practices for increasing crop and soil productivity, food security and incomes at household levels (Donovan and Casey 1998 and Mucheru-muna et al. 2013). Despite this, according to Stoorvogel and Smaling, (1990), Uganda´s rate of soil fertility depletion is one of the highest among countries in sub-Saharan Africa.

Reports by UBOS, (2007) indicated that 46% of the parcels in Uganda have poor soils. A parcel is a contagious piece of land with identical tenure and physical characteristics. It is entirely surrounded by land with other tenure or physical characteristics or infrastructure examples include roads, water, forest among others not forming part of the holding (UBOS 2007). The Central Uganda region has the highest percentage of parcels (19%) with poor soils whereas the Northern Uganda region had the highest percentage of parcels (i.e. 56%) with good soils (UBOS 2007). Despite this, Uganda's fertilizer use rate is among the lowest in sub-Saharan Africa. Smallholder farmers in Uganda on average use 1 and 7 Kg ha^{-1} of inorganic and organic fertilizers, respectively. This is quite low compared to 35 and 13 Kg of inorganic fertilizer use for Kenya, Malawi and Tanzania (Wallace and Knausenberger, 1997).

Water use for irrigation

The report by UBOS, (2007) indicated that the agricultural sector in Uganda is very much dependent on rain-fed agriculture. It further noted that overall, 96% of the parcels in Uganda depend on rain as their main source of water while 3% parcels use wetlands as their main water source and only 1% was use irrigation as their main source of water. Of the parcels that had irrigation as their main water source, the Central Uganda region had the highest percentage of 45%, followed by the Western region with 39%, the Eastern region with 14% and the Northern region with the lowest at 3% (UBOS 2007).

1.3 Climate change as a global challenge

Several reports have indicated that climate is changing globally. The report by the IPCC, (2001a) defines climate change as a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). That it may be due to natural internal processes or external forces, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Besides delaying achievement of the Millennium Development Goals in many of these countries, climate change will escalate hunger and human suffering (Davidson et al. 2003). It is concluded that global warming has accelerated in recent decades and there is additional evidence that most of the warming over the past 50 years is attributable to the increase in greenhouse gas emissions associated with human activities (IPCC 2001b). Reports by WMO (2009) indicated that the decade 2000-2009 is the warmest on record. Increasing temperatures influence weather and climate. It affects wind and rainfall patterns, and the types and incidence of severe weather events that may be expected to occur in an area (IPCC 2001b; IPCC 2014).

According to Stephen et al. (2007), changes in climate impacts on physical and biological systems. The vulnerability of ecological and human systems and the harmful and beneficial consequences for human well-being and sustainable development will be conditioned by exposures to other stresses and the capacity to cope, recover and adapt, all of which will vary across space and time. Our current actions and in the subsequent years could present risks of major disruption to economic-social activity, on a scale similar to those associated with the great wars and the economic depression of the first half of the 20^{th} century. It will be difficult to reverse these changes (Stern 2006).

The IPCC (2001c) concluded that the major climate change effects on the poorest countries will be include decline in crop yields in most tropical and sub-tropical regions inadequate water for production and altered insect pest incidence. Likewise, marine life and the fishing industry will also be severely affected in some places (IPCC 2014). Many countries in tropical and sub-tropical regions are expected to be more vulnerable to warming because additional warming will affect their marginal water balance and harm their agricultural sectors (IPCC 2014). The challenge will be greatest in Africa where information generation and dissemination is the poorest, technological advancement is slowest, and whose domestic economies depend heavily on agriculture (Mendelsohn et al. 2000).

1.4 Uganda’s preparedness to climate change impacts

Climate change disasters and associated impacts are already evident in Uganda. As reported in the Uganda NAPA, (2007), some of the outstanding climate change impacts in Uganda include the following:

- In each decade since 1950, average maximum and minimum temperatures have increased;

- Extreme heavy rainfall and associated floods resulting in loss of property and life; Variability in type, amount and frequency of rainfall which negatively affects agricultural productivity;
- Empirical evidence of severe droughts, with associated famine at household level; Receding and falling water levels in lakes and rivers particularly, Lake Victoria and River Nile;
- Increasing incidences of malaria in places such as Kabale where it was not prevalent before; and
- Receding ice caps on Mountain Rwenzori (*Mountains of the Moon*).

According to UBOS, (2007), climate change has grave implications for an agricultural sector with production activities entirely dependent on rainfall. Hence, reported climate and variability disasters such as prolonged droughts and unreliable rainfall patterns greatly impact negatively on livelihood and economy (NAPA 2007; DSIP 2010 and NDP 2010). The decline in crop yields due to prolonged droughts and unreliable rainfall patterns could leave hundreds of millions without the ability to produce or purchase sufficient food. Furthermore, droughts lower the country's productive capacity; reducing her agricultural exports, increasing food prices leading to food shortages, nutritional deficiencies and an unstable macro economy (Zake and Kaggwa 2007; Zake et al. 2010). For instance, the NAPA, (2007) noted uncertainty about the effects of increasing temperature rise on coffee production in Uganda. Thus a $2^{o}C$ raise in temperature will render the Lake Victoria basin unsuitable for robusta coffee production. This would have significant impactions on the country's gross domestic product and loss of livelihood of communities' dependent on coffee production. Uganda ratified the United Nations Framework Convention on Climate Change (UNFCCC). After ratification of the convention in 1992 (UNFCCC 2014), the Government of Uganda took several steps and actions at the policies and programs levels targeting to address climate change impacts through adaptation and mitigation. Some of the key policies and programs, which have been developed in this respect, are presented as follows:

National Agricultural Policy for Uganda (2011)

The development of the National Agricultural Policy for Uganda (2011) was spearheaded and coordinated by the MAAIF. The vision of the policy is, *'a competitive, profitable and sustainable agricultural sector.'* The policy recognizes climate change and variability as a major threat to development of the agricultural sector, thus it impacts negatively on agricultural production and food security. However, the climate change implications for agriculture production and food security are not well articulated in the policy. Furthermore, it does not clearly demonstrate policy commitments and practical strategies for mitigation and adaptation in the agricultural sector. Such strategies could include: Awareness creation among the farmers and other stakeholders in the agricultural sector about climate change impacts; Supporting and promoting appropriate technology for irrigation; Supporting and promoting agroforestry on farm; Supporting farmers to access drought resistant and early maturing crop varieties.

However, the policy proposed that the Environment and Natural Resources sector under the Ministry of Water and Environment should mainstream appropriate policy measures and programs on environmental management and natural resources. Furthermore, collaboration with MAAIF and other relevant ministries and agencies in mitigating the impact on agriculture in Uganda should be promoted. Overall, despite the Government of Uganda's efforts to advance climate change adaptation and mitigation at different levels through the several policy framework and instruments as described above, smallholder agricultural households are still vulnerable to climate change impacts (Morton 2007). This is largely due to inadequate policy implementation as a result of limited resources allocation and logistics for effective service delivery at different levels (UNDAC 2008 and NDP 2010).

Ugandan National Adaptation Program of Action (2007)

The development of National Adaptation Program of Action (NAPAs) by Least Developed Countries (LDCs) and Small Island Developing Countries (SIDS) was initiated at the seventh Conference of Parties held in Marrakech, Morocco following a general concern and recognition that LDCs and SIDS are the most vulnerable to adverse effects of climate change (UNFCCC 2002 and NAPA, 2007). The Ugandan NAPAs provides a framework for programs and projects (such as land degradation and management, community tree planting, water for production, indigenous knowledge and natural resources management) with actions to address and adapt to the impacts of climate change. In Uganda, the NAPA was completed and the total cost for its implementation is 39.8 billion US dollars. A strategy for its implementation was developed under the leadership of the Meteorological department, the current Climate Change Unit under the Ministry of Water and Environment. However, it is not yet effectively implemented due to limited funding. Thus, it is being piloted in 4 districts including: Bundibugyo, Nakansongola, Apac and Pallisa through funding from the Royal Danish Embassy (Climate Action Network Uganda 2014).

Development of the National development Plan for Uganda (2010)

The development and implementation of the National development Plan for Uganda (NDP) is coordinated by the National Planning Authority. The NDP envisions, *'a transformed Ugandan Society from a peasant to a modern and prosperous country within 30 years.'* The theme of the plan is, '*Growth, Employment and Social Economic transformation and Prosperity.'* The plan recognizes the climate change challenges regarding sustainable livelihoods, growth and development. It considers climate change as an enabling sector and outlines key strategies for management of climate change in Uganda as follows: Addressing legal and institutional frameworks necessary for the implementation of the United Nations Framework to Combat Climate Change (UNFCCC); Re-defining climate change as a development issue; providing and promoting incentives for clean development (NDP, 2010).

National Policy on Disaster Preparedness and Management (2010)

The overall aim of National Policy on Disaster Preparedness and Management (2010, p. 38) is to, *'establish efficient institutional mechanisms for integrating disaster preparedness and management into the socio-economic development planning processes at national and local government levels.'* The policy has clear strategies for advancing disaster preparedness and management. It provided for an institutional framework to ensure effective implementation. The Office of the Prime Minister is charged with the overall coordination for effective implementation of the policy at all levels.

Uganda Climate Change Policy (2013)

The process for development of the National Climate Policy for Uganda was concluded in 2012. The policy is scheduled for cabinet approval before the end of the financial year 2015/16. The policy development process was highly consultative. It involved several key stakeholders at the National and Local levels. It was coordinated by the Climate Change Unit under the Ministry of Water and Environment. The policy goal is, *'to ensure harmonized and coordinated action towards a climate resilient and sustainable low carbon development path for Uganda,'* (National Climate Change Policy 2013). The overall policy objective is, *'to ensure that all stakeholders with a role to play in the development of Uganda address climate change impacts and their causes through appropriate measures while promoting sustainable development,'* (Uganda Climate Change Policy 2013).

Considering that climate change impacts on all sectors differently, the policy identifies priorities for each sector to advance adaption and mitigation. With respect to the focus of the study, the policy priorities for advancement of adaptation and mitigation in the Agriculture and livestock and the Disaster risk management sectors are presented as follows: sector:

Agriculture and Livestock climate change adaptation priorities

- Promoting climate change adaptation strategies that enhance resilient, productive and sustainable agricultural systems;
- Supporting value addition and improve food storage and management systems in order to ensure food security at all times, as a factor of resilience.

Agriculture and Livestock climate change mitigation sector priorities

- Mainstreaming climate change mitigation issues in the efforts underway to promote and improve the management of natural resources, in order to ensure resilient, productive and sustainable agricultural systems with reduced greenhouse gas emissions;

Disaster Risk Management sector priorities

- Ensuring disaster mitigation and provide adequate preparedness for climate change–induced risks, hazards and disasters.

1.5 Climate change mitigation through agriculture

Agriculture should provide solutions by contributing to climate change mitigation (FAO 2010b; Starritt 2010 and World Bank 2013). This is through the concept of climate-smart agriculture based on a triple win scenario of food security, adaptation and mitigation (FAO 2010b and World Bank 2013). The farming system and management practices are important to achieve this. In Tables 1 and 2, the management practices based on existing available literature and the potential for C storage under selected farming systems, respectively are illustrated.

In respect to management practices, Savage, (2011) and Starritt, (2010) observed that the following management practices should be promoted: Intensive production through avoided opening up more land for agricultural production; Minimizing the carbon footprint of nitrogen fertilizer use and emissions of nitrous oxide; and Accumulation of soil organic matter and C through avoided tillage or no tillage, agroforestry, good management of residues, fixing nitrogen through biological processes. Besides the advancement in soil organic matter and C build up by these practices, there are other associated benefits. Some of the benefits include: improved rainfall capture and water retention by soils, increased crop yields, increased biodiversity within the farming system, use of less fuel, avoided soil compaction, and payment of carbon credits to farmers (Savage 2011 and Starritt 2010).

Table 1. Status of knowledge about improved agricultural practices and their potential impact on C storage.

Practice	**Estimated C storage in farming system**
Removing marginal land from production	0
Restoring degraded land	0
Reduced tillage	*
Decreasing biomass burning	*
Introducing trees into agricultural farming systems	*
Establishment of improved fallows	0
Irrigation water management	0
Introducing forage into rotations	0
Increasing grassland productivity	0
Erosion control	*
Increase soil Potassium and Phosphorus	0
Decreasing shifting cultivation	0
Improving animal waste management	0.85 ton C ha^{-1} $year^{-1}$ through compositing in vegetable crops in Egypt’s desert (Luske 2009)
Agroforestry (better management of trees on farm)	*
Better rice management (cultivars, water management)	0

C = Carbon; 0 Indicates no information available; # indicates that there is some information; * indicates inadequate information available. Adapted from IPCC 2001b; Verchot et al. (2007).

Table 2. Smallholder crop production tropical farming systems potential for climate change mitigation through carbon storage.

Farming system	Major crops and management practices	SC (Mg C ha^{-1} year^{-1})	CAB (Mg C ha^{-1} year^{-1})	Study Location	Methods	Key conclusions from study	References
Agroforestry homegardens	*Eucalyptus saligna*	*	16	Western Kenya	Allometric models	There is no relationship between the diversity of perennial plants growing on farm and the above ground carbon stocks.	Henry et al. (2008)
Agroforestry home gardens	Diverse tree species which produce fruits, vegetables, medicine and other woody products and timber. Some of the tree species include: *Cocos, Mangifera, Perkia, Gliricidia*, *Coffea robusta*	*	35	Indoneasia	Allometric models	C storage per area basis of home gardens and other smallholder agro-forestry systems accumulate significant amounts of carbon that is equivalent to that stored in tree based systems – including primary or secondary forests over similar time periods.	Roshetko et al. (2002)
Agroforestry	Intensive system comprising of *Faidherbia albida*, *Acacia spp*, *Adansonia digitata*, *balanites Aegyptica*, *Guiera Senegalensis* with Millet *(Panicum miliaceum)* and Sorghum as major crops	11	6	West-Central Agricultural region-Old Peanut Basin in Senegal	Century biogeochemical model	Potential changes in soil C over a 25 years period ranged from – 0.13 t C ha^{-1} under poor management to + 0.43 t C ha^{-1} under optimum agricultural intensification.	Tschakert, (2004)
Agroforestry - Alley cropping	10 years old system of *Erythrina Poeppigiana* intercropped with crops i.e. *Zea mays, Phaseolus and Manihotis esculenta*	*	5	Costa Rica	Allometric models	C input from crop residues is similar in both tropical and temperate agro-forests. Though the organic matter input is greater in the tropical system due to addition from pruning.	Oelbermann et al. (2004)
Agroforestry - Alley cropping	Maize (*Zea mays)*, Cotton *(Gossypium)* and Sorghum. Ridge tillage, Increased fertilizer application (manure, N and P) and	0.054	*	Mali, West Africa	Epic century models	Ridge management in combination with increased nutrient input substantially could increase crop yields and economic benefits to farmers and is also associated with significant soil carbon storage.	Doraisway et al. 2007

	residue management as key management practices.						
Dry land farming systems	Millet *(Panicum miliaceum)*, Groundnuts *(Arachis hypogaea)*. Farm yard manure application, maintenance of trees and zero tillage as key practices.	0.09 0.15 0.04	*	Nigeria, Sudan and Argentina	Century 4.0 and Roth C-263 soil organic matter models	These figures require verification by field studies.	Frage et al. (2007)
Shifting cultivation	Oil palm *(Eliaeis guineensis)* plantations of 15 years old	*	13	River Niah water shade, Malaysia	Allometric models/equations	Young fallows quickly regenerate to quasi-steady state following cultivation.	Rudbeck, (2006)
Coffee *(Coffea)* monoculture with fertilizer application at 250 Kg N ha^{-1} and 30 Kg P ha^{-}	Coffee *(Coffea)*	*	3.83 ± 1.98	Central Valley, Costa Rica	Allometric models	C stored in the phytomass was nearly 4 times larger in the Coffee *(Coffea)* agroforests than in the coffee *(Coffea)* monocultures.	Hergoualc'h et al. (2008)
Shaded Coffee (*Coffea*)-*Inga densiflora* agro-forest with fertilizer application at 250 Kg N ha^{-1} and 30 Kg P ha^{-1}	Coffee (*Coffea*) and *Inga densiflora*	*	14.59 ± 2.20	Central Valley, Costa Rica	Allometric models		Hergoualc'h et al. (2008)

N = Nitrogen; P = Potassium; C = Carbon; GHG = Greenhouse gas; * Indicates no information available. SC = soil carbon storage, CAB = C storage in above ground biomass (Mg C ha^{-1} year^{-1}). Author´s table.

1.5.1 Role of agroforestry in climate change adaptation and mitigation

Agroforestry plays an important role in climate change adaptation and mitigation (Savage 2011; and Starritt 2010). In these farming systems, C is stored in above-ground biomass for plants, crops and trees, and below-ground in the soil and roots (Hairiah et al. 2010). In this process, the trees and plant capture CO_2 from the atmosphere through photosynthesis. It is stored as cellulose in trunk, branches, twigs, leaves and fruits of trees and crops. In return trees and crops release oxygen into the atmosphere (Hairiah et al. 2010).

Seeberg-Everfeldt, (2010) emphasized that decomposing organic materials increase the amount of carbon stored in the soil, which is globally higher than the total amount in the vegetation and the atmosphere. He further noted that animals breathe in oxygen and breathe out CO_2 and through their faeces, C and N are released back to the soil.

According to Rao et al. (2007) agroforestry has been widely practiced over the ages as a means of achieving agricultural sustainability and addressing of the negative effects of agriculture such as soil degradation. Were as the significance of agroforestry regarding C storage and other CO_2 mitigating effects is being widely recognized, there is still paucity of quantitative data on specific systems. Most agroforestry systems are reported to have higher C stocks than agricultural monocultures. The expansion of agroforestry practices could yield higher C stocks in Africa's terrestrial systems (Roshetko et al. 2002; Albrecht and Kandji 2003; and Oelbermann et al 2004).

Based on reviews by Albrecht and Kandji (2003) and Nair et al. (2009), agroforestry systems C sequestration potential was estimated and falls within a wide range of between 12-228 and 1.3-173 t ha^{-1}, respectively. The quantity of C stored largely depends on the agroforestry farming system in place; environmental and socio-economic factors at play; tree species and management practices being used (Albrecht and Kandji 2003).

Besides, environmental benefits in the form of C sequestration, soil fertility maintenance, soil erosion control, regulation of micro-climate; agroforestry systems have other livelihood and economic benefits through diversification of agricultural systems thereby contributing to household income and food security (Neufeldt et al. 2009). According to Rao et al. (2007), ´agroforestry interventions provide the best "no regrets" adaptation measures in making communities resilient to the impacts of climate change.´

1.6 Smallholder farmers adaptation and mitigation to climate change

Assessments by the IPCC, (2001b) in respect to the world´s capacity for coping with and adapting to the inevitable impacts of climate change, revealed that the impacts of climate change are not evenly distributed. Communities who will be exposed to the worst of the impacts are also the least able to adapt to the associated risks (Smit et al. 2000 and Pulhin et al. (2006).

However, Adger et al. (2003) argue that communities in developing nations are not passive victims of climate change impacts. Earlier reports by Cross and Barker (1992) and Mortimore (1998) indicated that pastoralists in the West African Sahel have adapted to rainfall reductions of 25-33% in the twentieth century. Furthermore, resilience by smallholder farming communities to climate change impacts was reported in Bangladesh and indigenous hunting communities in the Canadian Arctic by Huq (2001) and Berkes and Jolly (2001), respectively.

Mendelsohn et al. (2000) reported that farmers in African have adapted to a degree of climate variability, but climate change may force large regions of marginal agriculture out of production in Africa. According to Chambers (1989), communities dependent on agriculture are practicing adaptation strategies to manage current climate variability. Some of the adaptation strategies reported include: less risk associated cropping systems; diversification of farm enterprises to maximize profits and spreading the risk; engagement in off-farm income-generating activities; selling of assets; and migration.

In Uganda, the impacts of climate variability have led communities to develop adaptation strategies (NAPA 2007). However, (NAPA 2007) further denotes that the frequency of events such as droughts, floods and storms was previously low and therefore adaptation mechanisms were not documented, developed nor popularized. Therefore, some of the adaption strategies need further development and improvement. The adaptation capacity to climate change impacts needs further strengthening considering that the climate change impacts are more persistent and extensive (Adger et al. 2003; Rao et al. 2007; Zake et al. 2010; and Zake 2009).

1.7 Research challenges

The smallholder farmers who are the most vulnerable to the climate change impacts and risks (Morton 2007) are not adequately supported for adaptation. This is largely due to the weak implementation of the National Policy on Disaster Preparedness and Management (2010) at village and community levels among other policies and programs (UNDAC 2008; UNCT-Ug 2011 and NDP 2010). Moreover, the farmers' perceptions (their concerns and views) on implementation of climate change disasters preparedness strategies are rarely integrated in policy implementation.

This situation is pushing smallholder farmers to try new ideas and or make adjustments in existing common agronomic techniques and practices (Adger et al. 2003). These could constitute innovations for adaptation and mitigation of the climate change impacts depending on the definition and characterization for innovations. However, in Uganda these innovations are not known among farmers and other research and development stakeholders. This is because they have not been identified, evaluated and documented. Consequently, they receive limited support from policies and programs implementation for further development to contribute to community climate change adaptation (NAPA 2007 and PROLINNOVA 2011). Furthermore, proven adaptation and mitigation innovations needs further strengthening considering that the climate change impacts are more persistent and extensive (Adger et al. 2003 and Rao et al. 2007).

Climate change and variability impacts have also affected major food and cash crops (e.g. bananas and coffee) in Uganda (NAPA 2007; Asten et al. 2011a; Rwenzori Regional Think Tank 2011). Thus, EMU (2007) reported decline in productivity of these and other crops (maize and cotton) in recent years due to climate variability especially prolonged droughts, crop pests and diseases was reported.

Furthermore climate variability will exacerbate soil fertility depletion, which is already a major constraint to agricultural production and food security for smallholder farming households in Uganda (Harvey et al. 2014). Earlier studies argued that agroforestry farming systems are more resilient to climate change and variability through improving soil fertility (Rao et al. 2007) and C storage compared (Oelbermann et al. 2004; Albrecht and Kandji (2003); and Roshetko et al. 2002) to monocultures. However, there is scarce information about the resilience of smallholder agroforestry farming systems and associated practices under the current and projected climate change and variability in Uganda.

1.8 Overall objective, specific objectives and research questions

In light of the above research challenges, this study contributes to the following overall objective and addressed the associated specific objectives.

Overall objective

To contribute to sustainable banana production farming systems for food security amidst climate change impacts among smallholder farmers in Central Uganda.

Under each specific objective the study was informed by a research hypothesis (H) and underlying research questions, both derived from the research challenges.

Specific objectives

(i) To examine farmers' perceptions of the implementation of climate change disaster preparedness policy strategies in Central Uganda;

H1: The inadequate implementation of climate variability disaster preparedness strategies at village and community levels triggers early actions by smallholder farmers to adapt to the shocks due to climate variability disasters.

Research questions

a) Does inadequate implementation of climate variability disaster preparedness strategies trigger early actions by smallholder farmers?

(ii) To evaluate smallholder farmers' innovations for climate change adaptation and mitigation under banana farming systems in Central Uganda;

H2: The occurrence of climate variability disasters (such as prolonged droughts, heavy rains) in Central Uganda triggers smallholder farmers to develop innovations to adapt and mitigate climate change impacts on their livelihoods. Thus, Climate change impacts motivate smallholder farmers to try out various things new practices in order to survive impacts. Some of these trials help them to go through stress periods due to climate change and they become part of the adaptation system and could be up-scaled across the farming community.

Research questions
(a) Do climate variability conditions trigger farmer innovations for adaptation and mitigation?
(b) What are the existing innovations for climate change adaptation and mitigation developed by smallholder banana farmers?

(iii) To evaluate the soil fertility status and C pools of smallholder BM and BCA farming systems in Central Uganda amidst climate variability.

H3: Smallholder BCA farming systems are more resilient to climate change impacts. Specifically, BCA should have higher levels of soil fertility parameters (total organic matter, organic C and N, exchangeable K, and plant-available P) and C pools (aboveground, belowground and in the soil) compared to BM farming system.

Research questions
(a) What is the soil fertility status of smallholder BM and BCA farming systems in Central Uganda under the current climate variability?
(b) How much C is stored in the aboveground, belowground and the soil (top and sub layers) under smallholder BM and BCA farming systems under the current climate variability conditions in Central Uganda?

Part II

2.0 Conceptual framework, research design and the methodological approaches

2.1 Conceptual framework for the study

The conceptual framework used in the study was derived from the theoretical framework called the, *'engine of adaptation science,'* according to Smit et al. (1999). It is based on the definition and description of adaptation specifically pointing out the needs for adaptation. As illustrated in Figure 1, ´clearly highlighting who and what adapts, the stimulus for which the adaptation is undertaken, and the process and form it takes, ´ (Smit et al. 1999). In this framework, adaptation was regarded as relative term considering the process and condition. It involves alterations from one thing (the system, system components and sub-components, activity, sector, community, or region) to another due to influence of the climate related stress or stimulus. Thus, ´the description of adaptation requires specifications for who or what adapts, the stimulus for which the adaptation is undertaken, and the process and form it takes, ´ (Smit et al. 1999).

The theoretical framework according to Smit et al. (1999) was chosen because it fits well with the study objectives and especially the process of climate change adaptation, the components and underlying climatic and non-climatic stimuli steering the process of adaptation and mitigation. Furthermore, the associated changes or outcomes within the system, sub-systems and responses by the different elements as common practices or innovations for climate change adaptation and mitigation. The elements in this framework were distinguished to clarify the concepts and treatments of adaptation and mitigation. All these elements are interdependent and interactive (Smit et al. 1999).

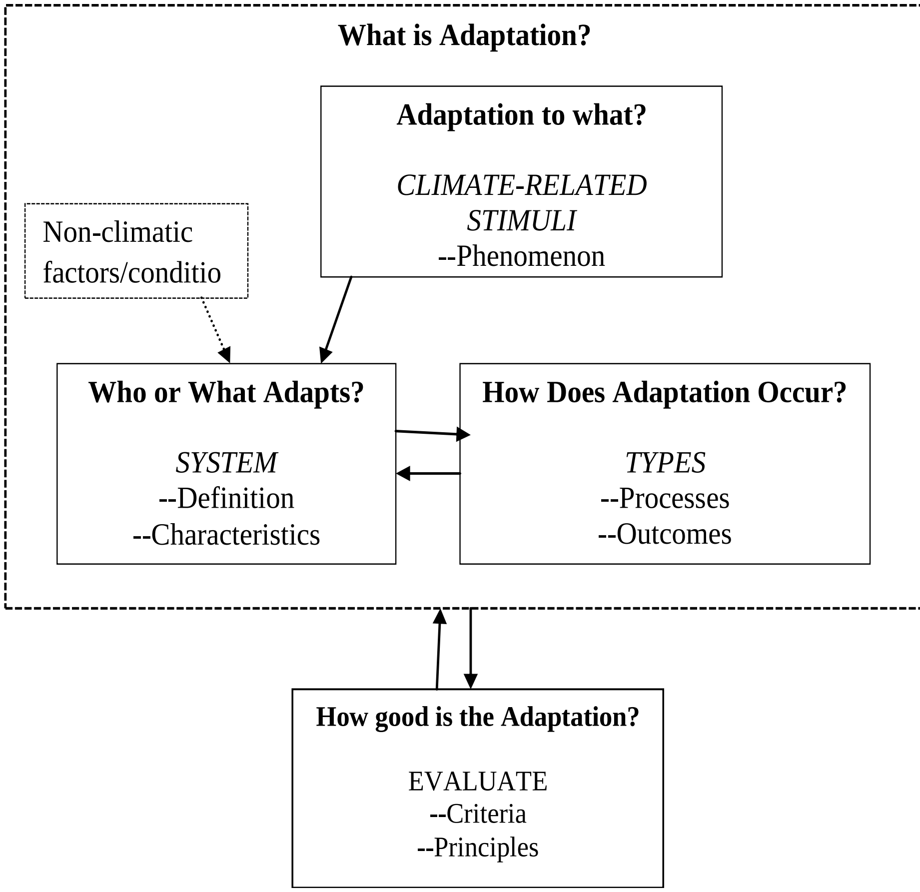

Figure 1. Adaptation to climate change and variability

Source: Derived from Smit et al., (2000).

For specific objectives (i) and (ii), the theoretical framework according to Smit et al. (1999) was applied with adjustments in the context of banana farming systems in Central Uganda and the possible paths to climate change adaptation and mitigation (Figure 2). The key variables impacting on the banana farming systems are temperature and precipitation. These constitute the climate change and variability stimuli. The impacts of the stimuli such as unpredictable rainfall patterns, prolonged droughts, floods, winds, and hailstorms destroy banana crops resulting in soil fertility depletion, low productivity and food insecurity. As a result, the farming system becomes destabilized.

As a result smallholder farmers try out various new practices in order to survive these shocks. However, farmers are assumed to be working together with other stakeholders including Government Agricultural Extension, Non-Government Organizations, Community-based Organizations, Private Sectors (Hocdé et al. 2006), Research Institutions in the farming systems so as to generate the adjustments necessary to achieve eventual success in adapting agriculture to climate change (IPCC 2007). With these interventions/innovations, the farming system and sub systems could reach a more stabilized/adoptive stage over time, for instance where the farmers could leave with the impacts of climate change and variability stimuli.

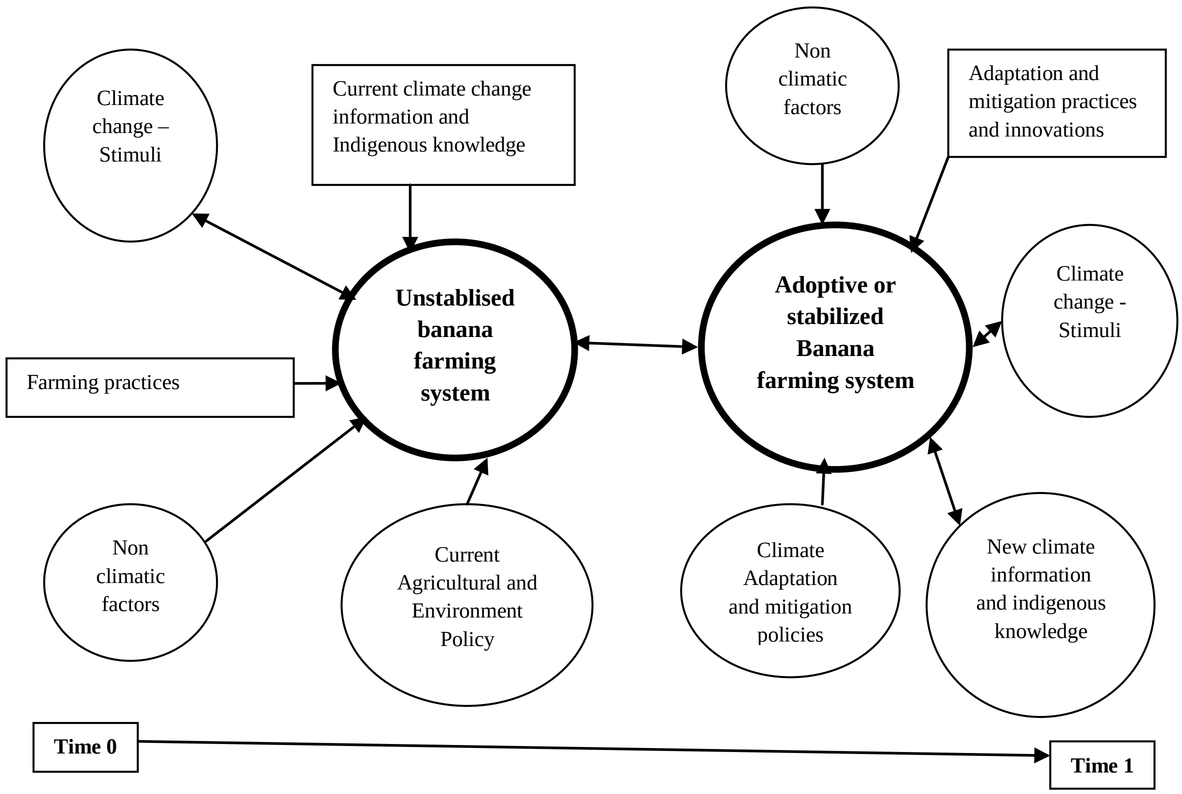

Figure 2. Conceptual framework for objective (i) and (ii) of the study

The type and size of the shapes does not imply any meaning.
Source: Author´s illustration.

The same theoretical framework (Smit et al. 1999) was used but with minor adjustments for study objective (iii), which focused on evaluation of the soil fertility status and C pools of smallholder BM and BCA farming systems in Central Uganda amidst current climate variability. The adjustments were done because this objective focused on more specific aspects within the farming community. Thus, a more specific conceptual framework was applied (Figure 3). The climate change and variability stimuli would impact on both banana farming systems and associated components particularly the soils sub-component. The farmer's management practices as response actions influence the soil sub-component parameters and characteristics. However, there are several factors at play and each contributes to the farming system´s resilience to climate change impacts. This objective targeted to answer research questions associated with soil fertility status and C pools under both banana farming systems.

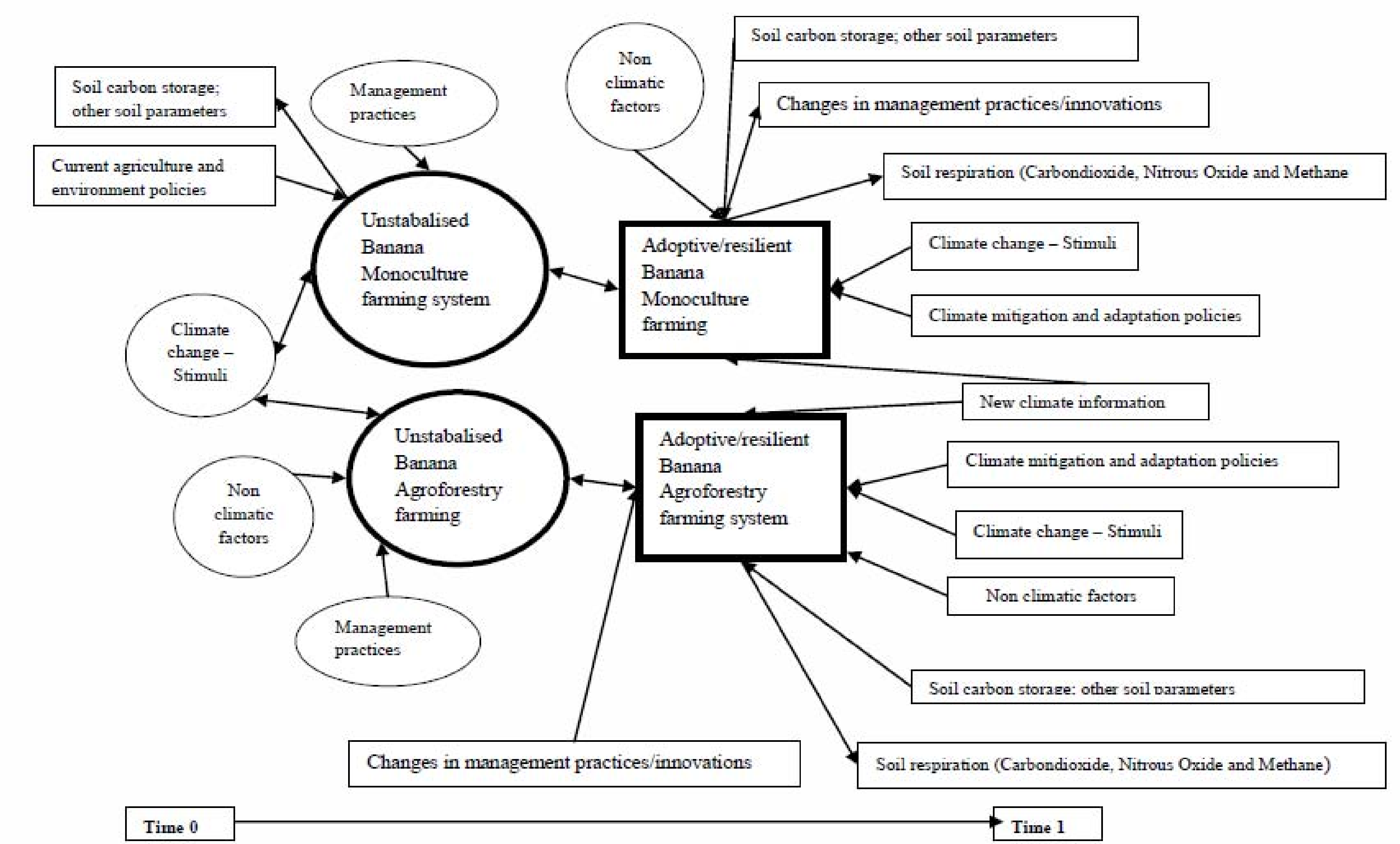

Figure 3. Specific conceptual framework for objective (iii) of the study.
The type and size of the shapes does not imply any meaning.
Source: Author´s illustration.

2.2 Methodology

2.2.1 Description of study area

The study was carried out within selected smallholder banana farming systems in Mpigi district located in Central Uganda in the Lake Victoria basin. The selection of Mpigi district for the study was based on the criteria that it is already affected by climate change impacts such as prolonged droughts and unreliable rainfall patterns (NEMA 2010) and hence has great implications for food security. Banana (*Musa spp*) was selected as the study crop because it's a major food and cash crop in the region.

Mpigi District comprises of undulating hills with deeply curved valleys. The hill summits lie between 1,182 and 1,341 meters above sea level. Seasonal and permanent streams drain much of the low-lying areas in the district (NEMA 2010). It's bordered by 5 districts including: Wakiso, Kalangala, Kalungu, Butambala and Mityana in the north and east, south, southwest, west and northwest, respectively. Mpigi town, where the district headquarters are located, lies approximately 37 kilometers, by road, west of Kampala, Uganda's capital and largest city.

Mpigi district is composed of Mawokota County with 6 sub counties namely: Mpigi Town Council, Kituntu, Nkozi, Buwama, Kammengo and Muduuma. Out of these, two sub counties were selected (i.e. Nkozi and Kituntu) as study sites based on the following criteria during the district stakeholders inception meeting: That the sub-county was a leading producer of bananas by smallholder farmers and was most affected by climate change disasters in the district. Both sub counties constituted the study site.

Mpigi district has a land area of 3715 km^2. Out of this; 719 km^2 is covered by water and wetlands, 1025 km^2 is arable land with approximately 38% covered by crops, and approximately 1100 km^2 covered by forests.

The district relief is generally made up of plateau and small undulating hills characterizing the Buganda surface and lying areas, drained by seasonal streams. The district two rainfall seasons (i.e. the first during March – May and the second during September-November) annually. The remaining months are generally dry. The mean annual rainfall is 1320 mm though in many areas of the lake zone it is between 1750 and 2000 mm. The average monthly days of rainfall are ten. The minimum and maximum temperature recorded in the district is 11^o C and 33^o C, respectively.

NEMA (2010) reported that climate change is a key challenge to agricultural activities in the district, with various impacts already reported including prolonged droughts spells, heavy rains, hailstorms that cause destruction of plantations increasing the risks of food shortages in many households and heavy dependence on environmental resources.

The population of the district was 407,790 people with a density of 139 people per square km in 2002 (UBOS 2006a). With an average population growth rate of 3.2% over the last decade, the population of the district is currently estimated at 454,800 people, 49 and 51% of these are males and females, respectively. The population density of the district is 230 per square km (UBOS 2011)

In the study site in Mpigi district, soils are generally Ferralsols with combinations of clay and sandy loams resulting in sandy clay loams. These soils are relatively fertile and favorable for crop production (NEMA 2010). However, most them require soil management attention for increased sustainable productivity. Soils on hills tend to be shallow and unsuitable for cultivation and are therefore mainly used for grazing under natural vegetation. Poor farming practices have resulted in loss of fertility in most parts of the district thus reducing productivity.

The major land use in the study area is subsistence agriculture. Agriculture land uses mainly comprise crop farming and animal husbandry. According to MAAIF (1995), Mpigi district lies in the Banana-coffee agro-ecological zone where the climate and soils have supported widespread cultivation of Banana and Coffee. The majority of farmers in Mpigi district are smallholder farmers on with land holding ranging between 1-3 acres. Various crops are cultivated including bananas (*Musa spp*), coffee rubusta (*coffee cenephora)*, cassava, sweat potatoes (*Ipomea batatas*), pumpkins (*Cucurbita maxima*), and cabbages (*Brassica olaracea*) among others. Bananas are a major food (NEMA 2010).

The NEMA (2010) report highlights that there has been a shift from the traditional food and cash crops. Thus, most of these crops are cash crops. Majority of the farmers are involved in subsistence farming. Coffee and horticultural crops especially tomatoes (*Solanum lycopersicum*), vanilla (*Vanilla planifolia*) and pepper (*Capsicum spp*) are the main cash crops.

Banana in the study area are cultivated in two major farming systems including banana monocultures and banana-coffee agroforestry systems (Figure 4). Therefore, the choice for bananas as the study crop is based on the criteria that they are major food crop in Uganda and Mpigi district and the Central region within the Lake Victoria basin in particular.

Livestock keeping is another key enterprise in the district. The major livestock types in Mpigi district include cattle, goats, sheep, poultry, pigs, local chicken, exotic chicken and rabbits. A large proportion of the households in the district (i.e. 78%) are involved in livestock rearing. The average land holding size for households engaged in livestock rearing is 3.5ha although small holders (0.8ha) contribute the greatest portion of the livestock farmers and these raise animals in semi-intensive farming and free-range systems of management for their livelihoods (NEMA 2010).

Banana (*Musa species*) monoculture farming system

Banana-coffee (*Musa species-coffee cenephora*) agroforestry farming system

Figure 4. Banana farming systems in the study site (Author´s photos).

2.2.2 Research methods

The following research methods and tools as presented in the subsequent sections were applied in order to achieve the study objectives:

Literature review

Literature review was done to understand the current state of knowledge about the study topic and research focus. Major emphasis was placed on aspects of climate change and related impacts with consideration of banana crop production and food security and associated policies and programs implementation in Uganda. The materials reviewed included: scientific journal articles, book chapters, conference proceedings, thesis, reports, government and inter-government documents and policy briefs. These were accessed online and from the BOKU Library. The information generated from the literature review was synthesized through content analyses in light of the research objectives and questions as described in section 1.8 This helped in the generation of useful information which was important in the development of survey research tools which were later used to generate the required information and data from the study.

Preparation of research tools

Research tools are important for information and data collection for research studies. In order to collect the required information and data considering the research study focus the following survey research tools were prepared prior to the field research studies in Central Uganda: Semi-structured survey questionnaires and check lists for key informants and focus group discussions.

The content in the survey research tools included key variables based on the following themes:

(i) Bio-data i.e. socio-economic information for smallholder farmers (respondents);

(ii) Soil management practices and planting density of major crops and plants under smallholder banana farming systems;

(iii) Soil fertility and crop productivity trends as perceived by smallholder farmers;
(iii) Climate change and variability impacts as perceived by smallholder farmers;
(iv) Community strategies and initiatives for advancement of climate change adaptation and mitigation;
(vi) Farmers' perceptions of the implementation of the climate variability disaster strategies.

Recognizing that climate change and variability impacts affect various gender categories (men, women and children) at the household level differently, given their differentiated roles and responsibilities (DFID 2008). The survey research tools were tailored to integrate gender issues as appropriate and this was followed through during administration of the tools.

The above survey tools were selected for use because of their appropriateness for application considering the scope and focus of the study. The check lists were useful for generation of information and data for validation and triangulation of data collected using the semi-structured survey questionnaires.

Site, farmers (respondents) and farm selection

Site selection
The study was conducted in two sub-counties (Nkozi and Kituntu) in Mpigi district. The decision for selecting these as the study site was made during a stakeholder's inception workshop held at Mpigi district headquarters (Figure 5). The stakeholders who participated in the inception meeting included district and sub-county technical and political officials from various sectors, including production, environment and community development. The two sub-counties were selected based on feedback from stakeholders that they are most affected by climate change disasters as compared to other sub-counties in the district. Thus, both sub-counties combined constituted the study site.

Farmer selection
The farmers involved in the interviews were selected randomly using existing lists of official registered farmers' groups at sub-county level. Furthermore, the farmers who participated in the focus group discussions were selected randomly from the list of respondents that were involved in the household survey.

Farm selection
Simple stratified sampling was used in the identification of the twenty smallholder farms on which the evaluation of soil fertility and C pools under banana farming systems amidst climate variability disasters impacts in the study sites was done. The banana monoculture and banana-coffee robusta agroforestry farming system, each constituted strata. The twenty farms were selected purposely from official existing lists of registered farmers at community level. The key consideration was that these farmers are engaged in production of banana and robusta coffee as major crops either as banana monoculture and banana-coffee robusta agroforestry and where located in the middle and middle lower slopes across the landscape. Ten farms were selected for each farming system and each farm was a replicate.

Data collection

Data were collected through application of the above research survey tools. They were pre-tested among at least 10 respondents before the full scale administration. This was done to address any problems with the tools particularly to clarify the questions and also to ensure that they covered all the required aspects in the study (Grimm 2010).

On-farm interviews were conducted among 133 farmers using the semi-structured survey questionnaires (Figure 7). These are referred to as respondents in the subsequent sections. Focus group discussions were conducted involving at least 15 respondents (Figure 6). These focused on farmers' perceptions of the implementation climate variability disaster preparedness strategies. Furthermore, interactive interviews were conducted with 30 key informants at national and local levels in the study area. These focused on key policy strategies for addressing climate change adaptation and mitigation with emphasis on farmers' innovations. The key informants who were engaged in the study were purposively selected from national and local level institutions in the Agricultural sector. The key institutions included Ministry of Agriculture, Animal Industries and Fisheries, Climate Change Unit, Ministry of Water and Environment, National Planning Authority, Civil Society, Private Sector, National Agricultural Research Institute, Development Partners, Local Government representatives, Uganda National Farmers Federation, Mpigi District Local Government technical and political leaders.

During the administration of the research survey tools, the involvement of men and women was considered to ensure equal engagement and re-presentation. This intended at generating independent feedback on how climate change has impacted on the different gender categories; how the different gender categories are adapting to the climate change impacts and the constraints faced by each gender category with respect to climate change adaptation; and their perceptions' of the implementation of the climate variability disaster preparedness strategies.

For instance, targeted focus group discussions were facilitated for both men and women independently. And were necessary both categories were involved in plenary discussions for further probing and validation of some of the responses. Likewise, the administration of the semi-structured questionnaires and key informant interviews targeted a fair representation of both men and women so that their respective views were obtained and documented.

Rainfall data over the last 15 years (i.e. for the period 1998-2012) were collected from Madu meteorological station in Mpigi district (Tropical Rainfall Measuring Mission Data 2013) to further understand the climate variations of the study site. Madu meteorological station was chosen because it located nearest to the study site.

Figure 5. Inception meeting with Mpigi district production sector stakeholders (Author´s photo).

Figure 6. Respondents engaged in a focus group discussion (Author´s photo).

Figure 7. Conducting semi-structured interviews (Author´s photo).

Soil sampling, soil sample preparation and laboratory analyses

Soil samples were randomly collected from 100x100 m plots located along flat plains within 20-40 m from the valleys on each of the selected 20 farms. These plots were located on areas with comparable soil type, variety of bananas and coffee, average rainfall amounts received to minimize variations among plots. In total twelve samples were collected from each farm. They were obtained from the top (A) and sub (B) layers using an auger and for each layer six replicates were obtained. Thus, 240 samples were collected in total from the twenty selected farms. These were transported immediately to the Soil and Plant Analytical Laboratories at National Agricultural Research Laboratories (NARL) where they were analyzed for total soil organic matter, total soil carbon, total N, plant-available P, exchangeable K, pH and soil texture.

Furthermore at each of the 20 selected farms, soil profiles were dug. For each profile, the depth of the top and sub soil layers was measured using a measuring tape. Soil core samples were collected for each soil layer up to the 20 cm depth. The diameter of the soil core was measured and fresh weight of each core sample was measured using a field scale. These values respectively, were used in the computation of the soil bulk density. Procedures as stipulated by Blake (1965) were used for the determination of the oven dry weight at 105^0 C and bulk density of the soil core samples at the Soil and Plant Analytical Laboratories at NARL.

Soil sample preparation

At NARL, the soil samples were prepared for analyses by drying at 45^{o} C for 2 days and later grounded and passed through a 2mm sieve. This preparation technique was used to avoid potential contamination of the samples and also for convenience considering that it allows judicious utilization of space during sample preparation.

Soil sample analyses

Soil texture was determined using the buoycous hydrometer method (Bouycous 1962). The total organic C was determined by the wet oxidation method as stipulated by Walkley and Black (1934). Total soil organic matter was derived from total organic C using a conversion factor of 1.73 based on an assumption that organic matter contains 58% organic C according to Nelson and Sommers (1996). Total N was determined through Kjeldahl digestion with procedures as stipulated by Nelson and Sommers (1972).

The exchangeable K and plant-available P were extracted using Mehlich III extraction method (Mehlich 1984). Soil pH was measured using procedures by Blakemore et al. (1987).

Determination of soil C stocks under banana farming systems

The computation of soil C per 100 m^2 with in the 20 cm depth in the two soil layers for the selected farms under respective banana farming systems required the use of mean total organic C and bulk density in the formulae according to Murphy et al. (2003). The results were extrapolated to generate soil organic C values on hectare basis (SOC stocks)

Determination of above and belowground biomass

Aboveground plant biomass (AGB) of major trees (coffee, bananas and key agroforestry tree species) was determined using allometric equations according to Arifin (2001) cited in (Hairiah et al. 2001); Segura et al. (2006); and Chave et al. (2005) for bananas, coffee and other tree species, respectively. The application of these equation required values of the diameter and height of the trees. The diameter and height of at least 3 for each major tree species randomly selected and located within100 m^2 of the selected smallholder farms was measured. Furthermore, the values of tree bulk density for each tree species as required for calculation using the allometric equations were obtained from the global wood density database (Zanne et al. 2009). The aboveground biomass results obtained were extrapolated to determine AGB on hectare basis (Mg ha^{-1}). Belowground biomass for each tree species was derived from the aboveground biomass using the equation developed by Cairns et al. (1997).

Determination of above and belowground plant C

The above and belowground plant C for each tree species was derived from above and belowground plant biomass, respectively. For bananas, coffee and other tree species the biomass was multiplied by 37.9% (Nurhayati et al. 2012), 45% (Noordwijk et al. 2002) and 50% (Becker et al. 2012), respectively. Total C pools under each were calculated as a sum of aboveground, belowground and soil carbon in the soil layers (top and sub).

Data analyses

Analyses of data generated using survey tools

The data generated using the semi-structured survey questionnaires were analyzed using Statistical Package for Social Sciences (SPSS) 16 (Field 2009) to generate percentages for various variables and correlations between the variables using Chi-square (X^2) and two tailed T-test. Gender was integrated in the analyses by disaggregating data sets based on males and females to understand the differentiated responses with respect to selected variables.

Data obtained through the focus group discussion and key informant check lists were synthesized through content analysis and used for validation of results from the semi-structured interviews.

The rainfall data collected was used to understand the rainfall trends by application of simple graphing techniques to plot rainfall quantities against the time scale. The trend lines were fitted using curve fitting techniques in micro-soft excel.

Analyses of data obtained from soil sampling and lab analyses

The results obtained from the soil sampling and laboratory analyses were examined for normality and homogeneity using Microsoft excel. Further analysis was done using a 2-factorial model to determine analysis of variance at 5% using GenStat 13. The sources of variation including farming system, soil level and interactions between farming system and soil level for each of the soil physical and chemical parameters were separated. Sigma plot was used to generate graphs for aboveground plant biomass and mean C pools under BCA and BM farming systems.

Preliminary research dissemination and feedback workshops

Three preliminary research dissemination and feedback workshops were conducted targeting key stakeholders in the study site. One workshop was conducted at Mpigi district headquarters were as two workshops were conducted at the sub-county headquarters. Hence, one was conducted at Nkozi and the other for Kituntu sub-county headquarters. The overall objective of these workshops was to disseminate reports with key research study findings and practical recommendations for implementation of subsequent appropriate actions by key stakeholders in the study site. And furthermore, to obtain stakeholder's feedback on the research finds.

The Mpigi district dissemination and feedback workshop was attended by 30 participants comprising of largely policy and decision makers from the technical and political discourse under the production sub sector (Figure 8). The sub-county workshops targeted the smallholder farmers and opinion leaders who participated in the study. At most each workshop engaged 50 participants (Figure 9). These included the 20 smallholder farmers who were selected purposively because they were involved in the survey and their farms were identified for soil sampling. Other participants were identified through random selection from the list of 133 smallholder farmers who were involved in the semi-structured interviews and focus group discussions.

Figure 8. Preliminary results dissemination workshop for Mpigi district stakeholders (Author´s photo).

Figure 9. Preliminary results dissemination workshop at Kituntu sub-county (Author´s photo).

Part III

3.0 Research Papers

Paper I

Farmers' perceptions of implementation of climate variability disaster preparedness strategies in Central Uganda.

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Farmers' perceptions of implementation of climate variability disaster preparedness strategies in Central Uganda

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This paper examines smallholder farmers' perceptions of the implementation of climate change disaster preparedness strategies in Mpigi district in Central Uganda. Furthermore, existing community early actions against climate change disasters were investigated. Data were collected through semi-structured interviews and focus group discussions at the community level. Using the Statistical Package for Social Sciences version 16, data obtained through semi-structured interviews were subjected to quantitative analysis to generate percentages for several variables and cross-tabulation analyses between selected variables. Farmers perceived prolonged droughts, increased pests and diseases outbreaks in crops and livestock as a consequence of climate change as the major climate change disasters. They considered the implementation of climate change disaster preparedness at community and village level as inadequate. This triggered implementation of various early actions by farmers as responses to climate change disasters. These actions constitute an informal community-based early warning system against climate change disasters.

Keywords: disaster management committees; policy implementation; community-based

1. Introduction

In Uganda, as in many other sub-Saharan countries, climate has become more variable and is projected to have major implications for agricultural development. This is a particular challenge for poor countries and their low resource endowed smallholder farmers that now have to cope with the additional shocks (Stern, 2006). In the third assessment report of the Intergovernmental Panel on Climate Change (2001, p. 872), 'climate variability is defined as the change in the mean state and other statistics (such as standard deviations, the occurrence of extremes) of the climate on all temporal and spatial scales beyond that of individual weather events'.

Climate change disasters such as prolonged droughts, floods, unreliable rainfall patterns, increased incidence of crop and livestock pests and diseases due to climate change are evident in many parts of Uganda and have significant implications for livelihoods and economic development (DSIP, 2010; National Adaptation Program of Action on Climate Change in Uganda [NAPA], 2007). The United Nations International Strategy for Disaster Risk Reduction (UNISDR, 2009, p. 9) defines disasters as 'serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and

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impacts, and which exceeds the ability of the affected community to cope by using its own resources'.

Statistics from the EM-DAT (2010) showed that on average more than 200,000 Ugandans were affected by climate change disasters annually. Unfortunately, the affected communities are inadequately prepared to manage the disasters when they occur. According to the UNISDR (2009, p. 21),

> disaster preparedness refers to the knowledge and capacities developed by governments, professional response and recovery organisations, communities and individuals to effectively anticipate, respond to and recover from the impacts of likely, imminent or current disaster events or conditions. It is based on sound analyses of disaster risks and good linkages with early-warning systems.

Along the same line, the International Federation of Red Cross and Red Crescent Societies (2008, p. 3) defines early warning early action 'as routinely taking humanitarian action before a disaster happens, making full use of scientific information on all time scales'. Braman et al. (2013) argue that it is a strategy used by disaster managers to benefit from forecast information at different time scales.

Notwithstanding, there are concerns that Uganda's disaster preparedness, early warning system and management are not very robust to effectively respond to the magnitude of impacts by climate change disasters (United Nations Assessment and Coordination of Humanitarian Affairs [UNDAC], 2008). Thus, the Centre for International Governance (2007) ranks Uganda as one of the most unprepared and most vulnerable countries in the world with respect to climate change impacts. Uganda's four million agricultural households are even more vulnerable to climate change impacts. This is the situation despite the existence of a national policy on disaster preparedness and management, which aims at establishing institutions and mechanisms for reduction of vulnerability of people, livestock, plants and wildlife to disasters in Uganda (National Policy on Disaster Preparedness and Management, 2010). Table 1 describes the key national policy strategies and implementing institutions to advance disaster preparedness at community, local and national levels.

The Ugandan National Policy on Disaster Preparedness and Management (2010) provides an institutional framework to ensure implementation of policy objectives and activities. The overall aim of the institutional framework, as stipulated in the National Policy on Disaster Preparedness and Management (2010, p. 38), is to 'establish efficient institutional mechanisms for integrating disaster preparedness and management into the socio-economic development planning processes at national and local government levels'. The key institutions at different levels that are clearly stipulated in the policy are presented in Figure 1. Their composition and responsibilities are illustrated in Table 2.

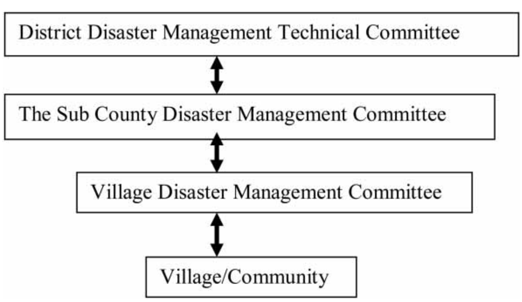

Figure 1. Institutional framework for implementation of disaster preparedness strategies in Uganda.

Table 1. Policy strategies and implementing institutions for disaster preparedness in Uganda.

Key climate variability disaster	Policy strategy to address the disaster	Key implementing institutions
Heavy storms	Creation of public awareness on the evacuation in circumstances of heavy storms; enforce adherence to proper building codes and standards; practice proper farming technologies; and establishment of early warning systems	Ministries of Water and Environment; Education and Sports; Local Government; Works and Transport; Agriculture, Animal Industry and Fisheries; Defence; Local Governments; Prime Minister's Office; Research Institutions; Community and Private Sector
Increased incidence of crop and livestock pests and diseases outbreaks due to climate variability	Vaccination and spraying; strengthen disease surveillance programmes; enforce regulations on movement of animals; undertake proper case management of the affected animals and plants	Ministries of Water and Environment; Local Government; Agriculture, Animal Industry and Fisheries; Lands, Housing and Urban Development; Local Governments; Prime Minister's Office; Research Institutions; Uganda Wildlife Authority; National Environment Management Authority; United Nations Agencies and Non-governmental Organisations; Community and Private Sector
Drought	Establish proper mechanisms for early warning and drought information dissemination; enforce implementation and compliance to environmental legislation; development of drought-resistant crops and livestock; upscale small-scale irrigation; and integrating disaster management programmes into the National Water Action Plan	Ministry of Water and Environment; Ministry of Local Government; Local Governments; Ministry of Agriculture, Animal Industry and Fisheries; Prime Minister's Office; Research Institutions; Ministry of Lands, Housing and Urban Development; National Forestry Authority; Research Institutions; Uganda Wildlife Authority; Non-governmental Organisations; Community and Private Sector

Source: National Policy on Disaster Preparedness and Management (2010).

The implementation of the policy in terms of preparedness for climate change disasters, especially at the village, household and sub-county levels, however, is still inadequate (United Nation Country Team in Uganda [UNCT-Ug], 2011). The farmers' perceptions (their concerns and views) on implementation of climate change disasters preparedness strategies are rarely integrated in policy implementation.

Moreover, climate change disasters affect community members differently (UK Department for International Development [DFID], 2008) and hence would respond in varied ways as a means of survival (Adger, Huq, Katrina, Conway, & Hulme, 2003). It is possible that smallholder farmers, local government institutions and non-governmental organisations, within their own capacities, implement certain early actions against climate change disasters at the community level. Mortimore and Adams (2001) reported that farmers in the West-African Sahel region evolved strategies (such as integration of livestock with crops; diversification of livelihoods) as response to prolonged droughts. In Central Uganda, similar evidence is not yet available.

Table 2. Key institutions for disaster preparedness at local level in Uganda.

Key institutions for disaster preparedness	Composition	Level of operation	Responsibilities
District Disaster Policy Committee (DDPC)	The DDPC is composed of the following: District Executive Committee, Resident District Commissioner, Disaster Management Officer, District Police Commander, District Internal Security Officer, and Representative of the Army and the Mayors/Local Council III Urban Chairpersons of Town Councils. It is chaired by the District Chairman were as the Chief Administrative Officer is the Secretary	District/local government	(i) Provides policy direction to the District Disaster Preparedness Management Technical Committee and District Councils (ii) Facilitates linkages between disaster preparedness committees at national and local levels (iii) Monitoring implementation of disaster response activities in the district
Sub-County Disaster Management Committees (SDMC)	The SDMC comprises of the sub-county executive, sub-county police, technical staff and partners in the sub-county. This committee is chaired by the Sub-County Local Council III Chairperson and the Sub-County Chief is the Secretary	Sub-county	(i) Participating in preparedness and management of disasters in the sub-county (ii) Participating in vulnerability assessment and mapping in the sub-county (iii) Mobilisation, sensitisation and monitoring before, during and after the occurrence of disasters
Village Disaster Management Committee (VDMC)	The VDMC comprises of all adult members of the village. The Local Council I executive is the lowest unit of disaster preparedness and management. It is chaired by the Local Council I Chairperson	Village	(i) Assist in the reconstruction of the history of disasters in the area (ii) Collecting early warning information and disseminating it to the sub-county and district level (iii) Educating community members on risks and hazards which may potentially cause disasters (iv) Participating in the implementation of disaster preparedness action plans

Source: National Policy on Disaster Preparedness and Management (2010).

Therefore, the objective of the study was to examine farmers' perceptions of the implementation of climate change disaster preparedness policy strategies. Furthermore, the existing community early actions against climate change disasters were identified.

2. Research design

2.1. *Overview of the study site*

The study was conducted in Mpigi district (00°14′N 32°20′E) located in Central Uganda (Figure 2). Mpigi district has 3715 km^2 of land area. Of this, 1025 km^2 is arable land with approximately 38% covered by crops (National Environment Management Authority [NEMA], 2010).

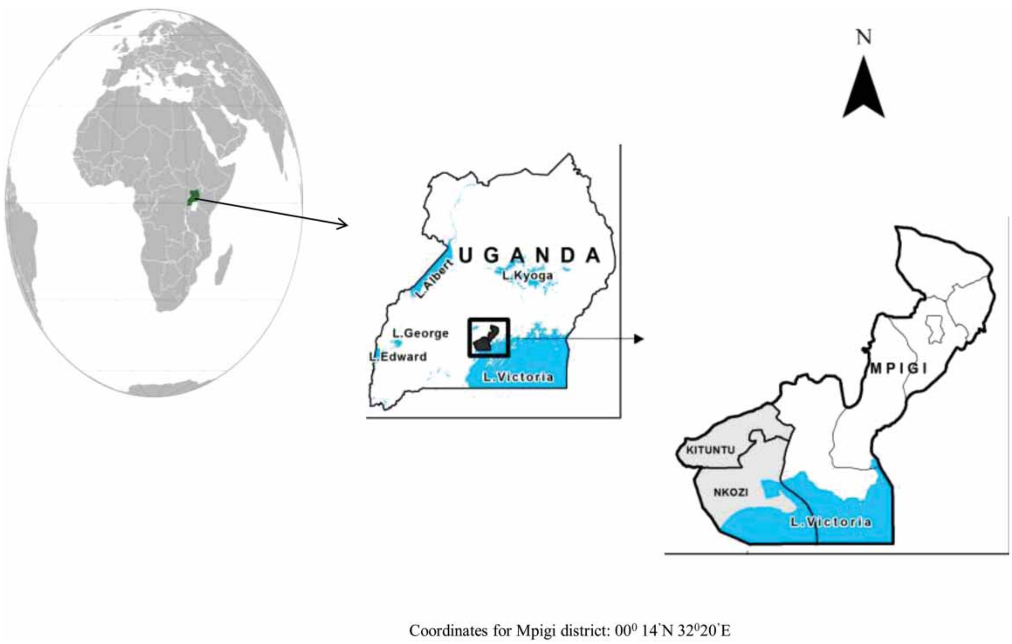

Figure 2. Location of study site in Mpigi district, Central Uganda.
Source: Adapted from Google images (accessed: 12/10/2013)

The district lies at an altitude range of 1182–1341 m above the sea level. A bimodal rainfall pattern provides moisture in March–May and September–November, with a mean annual rainfall of 1320 mm and 10 average monthly days of rain. The minimum and maximum temperatures in the district are 11°C and 33°C, respectively. However, climate change is a key challenge to agricultural activities with various disasters, including prolonged droughts, heavy rains and hailstorms that cause destruction of plantations, increasing the risks of food shortages in many households (NEMA, 2010). According to the National Policy on Disaster Preparedness and Management (2010), drought is defined as the long-term shortage of water usually caused by dry weather conditions.

With an average population growth rate of 3% over the last decade, Mpigi district has a population density of 230 people per km^2. This is higher than the national average at 167. The proportion of males to females is 49% and 51%, respectively (Uganda Bureau of Statistics, 2011).

The District State of Environment Report by NEMA (2010) identified subsistence agriculture as the major land use in Mpigi district. Crop and animal husbandry are key enterprises. The district lies in the banana–coffee (*Musa species–Coffea cenephora*) agro-ecological zone, where the climate and soils have supported widespread production of banana and coffee (Ministry of Agriculture, Animal Industries and Fisheries, 1995). The majority of farmers in the district are smallholders. They constitute about 18% of the district population (i.e. 75,208) and each has a land holding ranging between 0.4 and 1.2 ha (Uganda Bureau of Statistics, 2011). The crops cultivated include: bananas, coffee, cassava (*Manihot esculenta*), sweat potatoes (*Ipomoea batatas*) and vegetables. Bananas are a major food crop. There is a shift from the traditional food and cash crops, with most of these crops acting also as cash crops. The main cash crops include banana, coffee and vegetables (NEMA, 2010).

The selection of Mpigi district as a study site was based on the criteria that it is already affected by climate change disasters that negatively impact on livelihoods of smallholder banana–coffee farming communities. The study was conducted in two sub-counties (Nkozi and

Kituntu) in Mpigi district. These sub-counties were selected during an inception meeting, which involved key stakeholders in the district. The stakeholders included district and sub-county technical and political officials from various sectors, including production, environment and community development. The sub-counties were selected based on feedback from stakeholders that they are most affected by climate change disasters as compared to other sub-counties in the district. Thus, both sub-counties combined constituted the study site.

2.2. *Sampling design, data collection and analyses*

Figure 3 depicts the components of the research methodology used in the study. The methodology involved literature review, selection of respondents, data collection, analyses and synthesis.

2.2.1. *Sampling design*

Simple, random sampling design was used to select respondents for the household survey using the existing lists of official registered farmers' groups at sub-county level. Data on climate change disasters and implementation strategies at community level were collected using semi-structured household survey questionnaires. These were pre-tested before administering them among 133 smallholder farm households. These are also referred to as respondents in the subsequent sections. The first author conducted focus group discussions among respondents to build consensus and validation of particular perceptions of respondents from the household survey. In total, two focus group discussions were conducted. Each discussion involved 15 respondents (including men and women) selected randomly from the list of respondents that were involved in the household survey. The discussions focused on community perceptions about the role of key actors in strengthening implementation of climate change disaster preparedness.

2.2.2. *Data analysis*

The data collected through the semi-structured household survey questionnaires were analysed using the Statistical Package for Social Sciences version 16, to generate percentages for several variables and determine the existence of relationship between selected variables using the Pearson's chi-square tests based on Asymp. Sig. (two-sided) at 5%. The data from the focus group discussions were documented and synthesised for triangulation of respondent's perceptions of the role of key actors in strengthening implementation of climate change disaster preparedness as generated in the survey data.

3. Results

3.1. *Existing climate change disasters at community level*

Both male and female respondents perceive prolonged droughts, increased incidence of pest and diseases outbreaks in crops and livestock due to climate change as the major disasters that occurred in their community in the last 2–5 years (Table 3). Feedback from focus group discussions showed that droughts, which used to normally last for 3 months, have currently extended to 4–6 months period.

Data in Table 4 show that respondents' perceptions of climate change disasters that occurred in their community in the last 2–5 years based on wealth ranking (using size of land ownership as a measure) were comparable.

Data in Table 5 show a significant relationship between respondents' perceptions of occurrence of climate change disasters in the last 2–5 years and engaging in off-farm income-generating

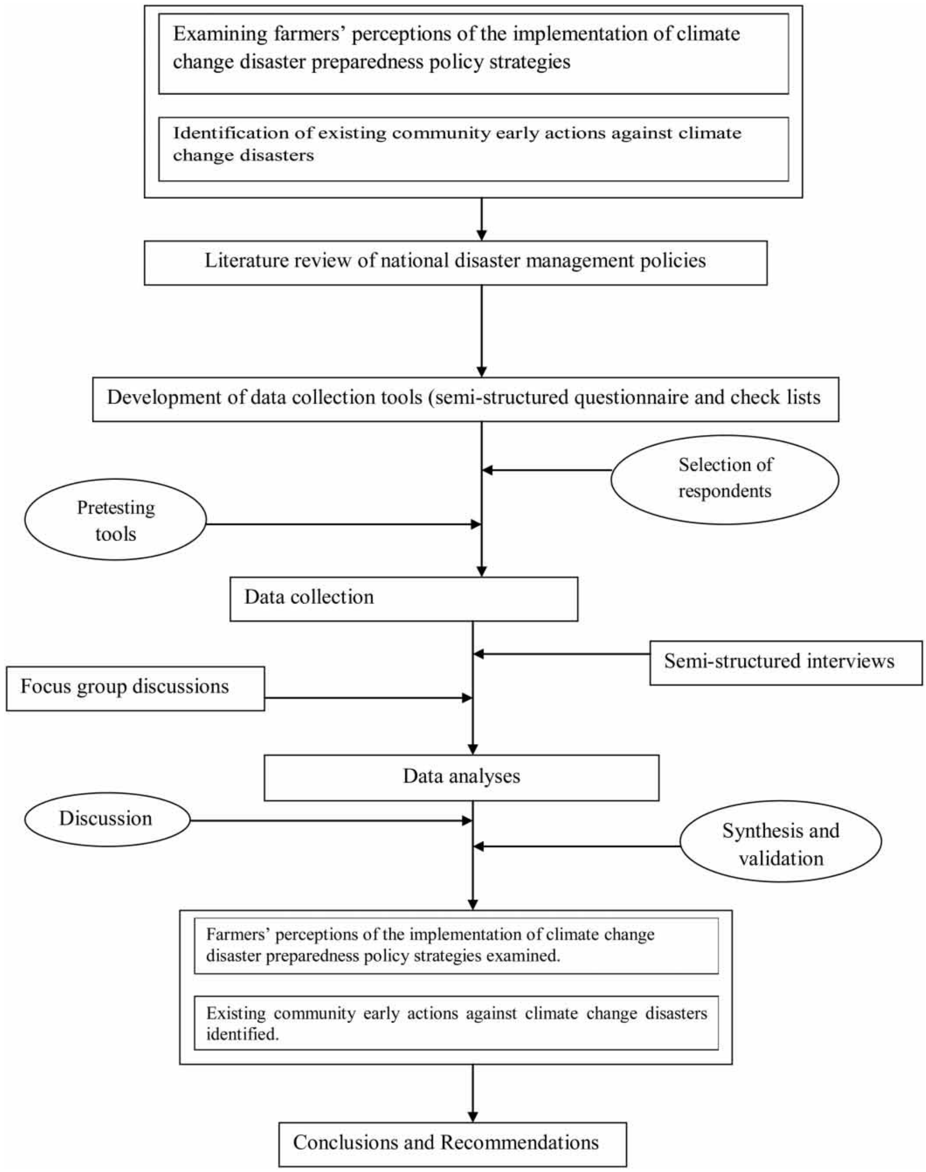

Figure 3. Components of the study methodology.

activities. The respondents who perceived occurrence of heavy rains with hailstones as disasters are two times more likely to engage in off-farm activities for income generation compared to those who had a different perception.

3.2. *Existing actors in the implementation of community disaster preparedness strategies*

Both male and female perceive non-governmental organisations, the local council, the radio station and agricultural officers as the major existing actors in the implementation of climate change disaster preparedness strategies at community level (Table 6). The perceptions of male

Table 3. Respondents' perception of climate change disasters that occurred in Mpigi district in the last 2–5 years based on gender ($N = 133$).

Climate change disaster	Yes: Male (%)	Yes: Female (%)	*n*	df	Pearson χ^2 value	*P*
Prolonged droughts	72	28	104	1	0.01	1.0
Increased incidence of pests and diseases outbreaks in crops and livestock due to climate variability	76	24	66	1	0.84	0.4
Heavy rains with strong winds	77	23	48	1	0.80	0.3
Heavy rains with hailstorms	74	26	43	1	0.69	0.2

Notes: *N*, total number of respondents interviewed; *n*, number of respondents whose perception is 'Yes'; df, degrees of freedom; *p*, Asymp. Sig. (two-sided) at 5%; *, the relationship between the two variables is significant.

Table 4. Respondents' perception of climate change disasters that occurred in Mpigi district in the last 2–5 years based on wealth ranking ($N = 133$).

Climate change disaster	Yes: Rich (%)	Yes: Medium (%)	Yes: Poor (%)	*n*	df	Pearson χ^2 value	*p*
Prolonged droughts	8	82	10	104	2	3.2	0.2
Increased incidence of pests and diseases outbreaks in crops and livestock due to climate change	12	74	14	66	2	4.6	0.1
Heavy rains with strong winds	2	90	8	48	2	4.6	0.1
Heavy rains with hailstorms	5	84	11	43	2	0.8	0.7

Notes: *N*, total number of respondents interviewed; *n*, number of respondents whose perception is 'Yes'; df, degrees of freedom; *p*, Asymp. Sig. (two-sided) at 5%; *, the relationship between the two variables is significant.

Table 5. Respondent's perceptions of occurrence of climate change disasters in the last 2–5 years vs. engaging in off-farm income-generating activities as a result of climate variability ($N = 133$).

Climate change disaster that occurred in community in the last 2–5 years	Engaging in off-farm income-generating activities as a result of climate change disaster: Yes (%)	No (%)	*n*	df	Pearson χ^2 value	*p*
Prolonged droughts – Yes	75	84	104	4	0.023	<0.01*
Increased incidence of pests and diseases outbreaks – Yes in crops and livestock due to climate change	49	51	66	4	0.023	<0.01*
Heavy rains with strong winds – Yes	36	39	48	4	0.023	<0.01*
Heavy rains with hailstones – Yes	38	22	43	4	0.024	<0.01*

Notes: *N*, total number of respondents interviewed; *n*, number of respondents whose perception is 'Yes'; df, degrees of freedom; *p*, Asymp. Sig. (two-sided) at 5%; *, the relationship between the two variables is significant.

Table 6. Respondents' perceptions on existing actors in the implementation of climate change disaster strategies in Mpigi district ($N = 133$).

Existing actors	Yes		n	df	Pearson χ^2 value	p
	Male (%)	Female (%)				
Non-government organisations	69	31	102	2	2.8	0.25
Local council	69	31	89	2	1.8	0.40
Radio station	80	20	84	2	8.5	0.01*
Agricultural officers	72	28	64	2	0.4	0.82
Fellow farmers	71	29	62	2	0.4	0.81
Veterinary officers	70	30	20	2	0.4	0.81
Disaster management committees	67	33	15	2	0.6	0.74
Meteorological officer	100	0	4	2	2.0	0.36

Notes: N, total number of respondents interviewed; n, number of respondents who perception is 'Yes'; df, degrees of freedom; p, Asymp. Sig. (two-sided) at 5%; *, the relationship between the two variables is significant.

and female regarding radio station as a key actor are significantly different at 5%. Thus, men are four times more likely to consider radio station as a key actor compared to women.

In Figure 4, we derive a presentation of existing key actors and how they interact with farmers at the household level during implementation of climate change disaster strategies in Mpigi district. This illustration is based on the interpretation that actors whom a higher percentage of the respondents identified as existing actors in this respect are considered as the key actors. Thus, they reach more smallholder farmers at the household level. Therefore, non-governmental organisations, local council, radio station and agricultural officers are the major existent actors.

3.3. *Early actions implemented at the community level*

The majority of respondents interviewed perceive that early actions against climate change disasters are being implemented at the community level. The four most important early actions are farmer-led (Table 7).

The relationship between respondents' perceptions of existing actors in the implementation of climate change disaster strategies and planting indigenous drought-resistant crops as an early action implemented by farmers against prolonged droughts is significant at 5%. Thus, the respondents who perceive agricultural officers as non-existent actors in the implementation of climate change disaster strategies are one and half times more likely to plant indigenous drought-resistant crops as early actions against prolonged droughts compared to those who have a different perception (Table 8).

The relationship between respondents' perceptions of key actors in the implementation of climate change disaster strategies and construction of soil- and water-conservation trenches on farms as an early action implemented by farmers against prolonged droughts is significant at 5%. Thus, the respondents who perceive disaster management committees as non-existent actors in the implementation of climate change disaster strategies are one time more likely to construct soil- and water-conservation trenches on their farms as early actions against heavy rains compared to those who have a different perception (Table 9).

3.4. *Key challenges for the implementation of climate change disaster preparedness strategies in Mpigi district*

Both male and female consider lack of climate change disasters forecast, lack of logistics and funds for disaster preparedness and lack of community early warning action plans as the key

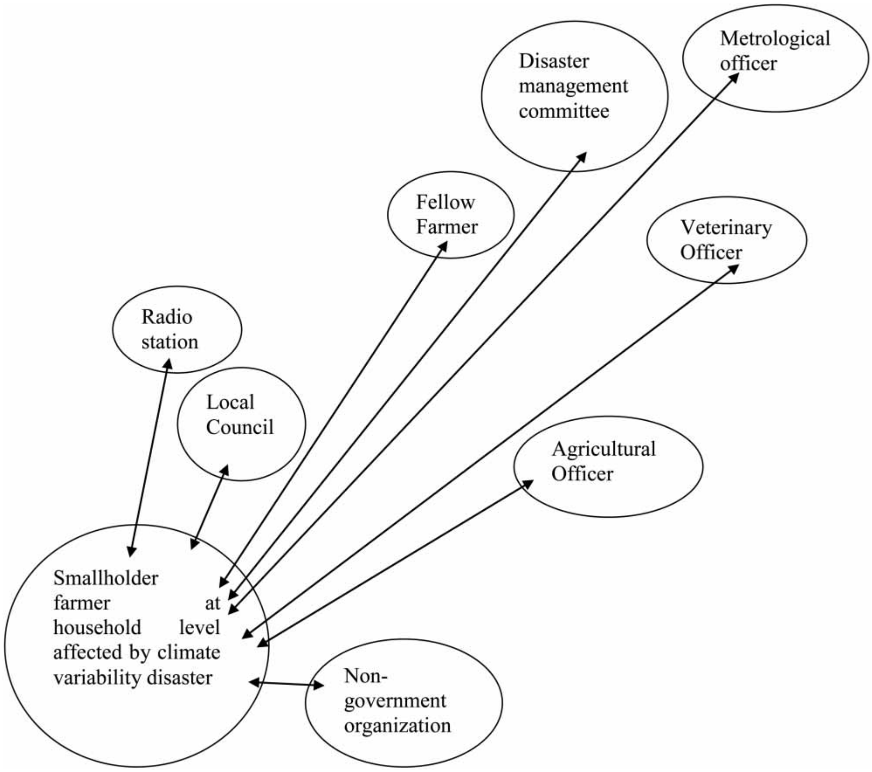

Figure 4. Interaction between key actors and farmers in the implementation of community early warning actions in Mpigi district. ⟷ The double-edged arrow depicts an interactive relationship between the smallholder farmer and the existent key actor at the household level. The length of the arrow from the farmer at the household level implies the number of farmers reached by the actor during implementation of climate change disasters strategies. Hence, the longer the arrow, the smaller the number of farmers reached by the actor. The shorter the arrow, the bigger the number of farmers reached. It is assumed that there is an interaction between the key actors on various community-development issues. The level of interaction is not indicated because it was not investigated in the study.

Table 7. Respondents' perceptions of early actions implemented against climate change disasters in Mpigi district based on gender ($n = 133$).

Early actions	Yes (%)
Early actions implemented against climate change disasters	85
Planting indigenous drought-resistant crops (arrow roots and upland yams)	64
Planting improved drought-resistant and early maturing crop varieties	62
Construction of soil- and water-conservation trenches on farms	62
Dissemination of climate change forecasts and action to take	57
Planning meeting by disaster management committees at village and sub-county levels	28
Training disaster management committees at community and sub-county levels	9

Notes: *n*, Number of respondents; scientific names for arrow roots and upland yams are *M. arundinaceae* and *Dioscorea* spp., respectively.

Table 8. Respondents' perceptions on existing actors in the implementation of disaster strategies at community level vs. planting indigenous drought-resistant crops as early action by farmers against climate change disasters ($N = 133$).

Existing actors in the implementation of disaster preparedness strategies	Planting indigenous drought-resistant crops (such as arrow roots and upland yams) as early action implemented by farmers against prolonged droughts					
	Yes (%)	No (%)	n	df	Pearson χ^2 value	p
Agricultural officers – No	54	35	64	6	0.024	<0.01*
Non-governmental organisations – No	14	28	102		0.024	<0.01*
Veterinary officer – No	78	85	20	6	0.024	<0.01*
Meteorological officers – No	89	98	4	6	0.024	<0.01*
Disaster management committees at village and sub-county levels – No	79	94	15	6	0.024	<0.01*
Local council – No	27	31	89	6	0.024	<0.01*
Radio station – No	28	40	84	6	0.024	<0.01*

Notes: N, total number of respondents interviewed; n, number of respondents whose perception is 'No'; df, degrees of freedom; p, Asymp. Sig. (two-sided) at 5%; *, the relationship between the two variables is significant; scientific names for arrow roots and upland yams are *M. arundinaceae* and *Dioscorea* spp., respectively.

Table 9. Respondents' perceptions of existing actors in the implementation of disaster strategies at community level vs. construction of soil and water conservation trenches as early action by farmers against climate change disasters ($N = 133$).

Existing actors in the implementation of disaster preparedness strategies	Construction of soil- and water-conservation trenches on farms as early action implemented by farmers against heavy rains					
	Yes (%)	No (%)	n	df	Pearson χ^2 value	p
Agricultural officer – No	46	51	64	6	0.023	<0.01*
Non-governmental organisations – No	15	27	102	6	0.023	<0.01*
Veterinary officers – No	80	81	20	6	0.023	<0.01*
Meteorological officer – No	82	90	4	6	0.024	<0.01*
Disaster management committees – No	94	90	15	6	0.024	<0.01*
Local council – No	28	29	89	6	0.024	<0.01*
Radio station – No	34	29		6	0.024	<0.01*

Notes: N, total number of respondents interviewed; n, number of respondents whose perception is 'No'; df, degrees of freedom; p, Asymp. Sig. (two-sided) at 5%; *, the relationship between the two variables is significant.

Table 10. Key challenges for implementation of community change disaster strategies in Mpigi district as perceived by male and female respondents ($N = 133$).

Key challenge	Yes: Male (%)	Yes: Female (%)	n	df	Pearson χ^2 value	p
Lack of climate change disasters forecast	73	27	109	1	0.03	0.87
Lack of logistics and funds for disaster management	73	27	121	1	0.20	0.66
Lack of community early warning action plans at village and sub-county levels	68	32	91	1	2.35	0.13
Misinterpretation of climate change forecasts	65	35	49	1	1.83	0.63
Loss of trust in climate forecasts by the community	75	25	40	1	0.23	0.63
Inaccuracy of climate change forecasts	76	24	38	1	0.45	0.50

Notes: N, total number of respondents interviewed; n, number of respondents whose perception is 'Yes'; df, degrees of freedom; p, Asymp. Sig. (two-sided) at 5%; *, the relationship between the two variables is significant.

challenges for the implementation of community climate change disaster preparedness strategies. However, their perceptions are similar at 5% (Table 10).

3.5. *Key opportunities for strengthening the implementation of climate change disaster preparedness strategies in Mpigi district*

Both male and female respondents perceive presence of farmers' groups, existence of local council leadership and existence of non-governmental organisations working on disaster management issues as the outstanding opportunities for strengthening the implementation of climate change disaster preparedness strategies. However, their perceptions are similar at 5% (Table 11).

3.6. *Possible actions for strengthening community disaster preparedness*

Respondents consider the increase in awareness of community about importance of climate change forecasts and development and implementation of community-based disaster preparedness plans as the outstanding possible actions for strengthening community disaster preparedness (Table 12).

Table 11. Key opportunities for implementation of community climate change disaster strategies in Mpigi district as perceived by male and female respondents ($N = 133$).

Key opportunity	Yes: Male (%)	Yes: Female (%)	n	df	Pearson χ^2 value	p
Presence of farmers' groups	74	26	125	1	2.09	0.15
Existence of local council leadership	74	26	123	1	2.65	0.10
Existence of non-governmental organisations working on disaster management issues	72	28	114	1	0.03	0.87
Presence of religious and cultural institutions	76	24	75	1	1.25	0.26
Presence on community radios	78	22	40	1	0.81	0.37
Existence of disaster management committees	80	20	25	1	0.94	0.33

Notes: N, total number of respondents interviewed; n, number of respondents whose perception is 'Yes'; df, degrees of freedom; p, Asymp. Sig. (two-sided) at 5%; *, the relationship between the two variables is significant.

Table 12. Key actions for strengthening implementation of community climate change disaster preparedness strategies in Mpigi district as perceived by respondents ($n = 133$).

Possible action	Yes (%)
Increase awareness of the community stakeholders about the importance of climate forecasts	94
Development and implementation of community disaster preparedness plans	82
Increase access to forecasts about climate change disasters	69

Note: n, number of respondents interviewed.

3.7. *Community perceptions of key stakeholders that should be involved in the implementation of climate change disaster preparedness strategies*

Respondents perceive non-governmental organisations, agricultural officers, local council, farmers' groups, radio, cultural institutions and religious institutions as the outstanding and major stakeholders, respectively, that should be involved in the implementation of community climate change disaster preparedness strategies (Table 13). The reasons why the respondents perceive these as key stakeholders were generated during focus group discussions and are presented in Table 14.

4. Discussions

The respondents' perceptions on major climate change disasters occurring in their community in the last 2–5 years (Table 3) concurred with earlier reports on key disasters in Central Uganda and other parts of the country at large. These reports highlighted prolonged droughts, heavy rains with hailstones/strong winds, increased incidence of pests and diseases as a consequence of climate change as the key disasters in Uganda (NAPA, 2007; National Disaster Preparedness and Management Policy, 2010; NEMA, 2010; UNDAC, 2008). The climate change disasters indeed impact on community livelihoods. The impacts ranged from destruction of crops and death of livestock, leaving households without food. However, the reported impacts have not reached extremes such as loss of property and lives (NAPA, 2007; NEMA, 2010).

The similarity in perceptions of the respondents belonging to different wealth ranks regarding occurrence of major disasters in their community in the last 2–5 years (Table 4) depicted that climate change disasters affect everyone in the community. This is in line with the findings by

Table 13. Key stakeholders that should be involved in the implementation of climate change strategies at community level in Mpigi district as perceived by respondents ($n = 133$).

Key stakeholder	Yes (%)
Non-governmental organisations	96
Agricultural officers	95
Local councils	94
Farmers' groups	90
Radio station	83
Religious institutions	72
Cultural institutions	71
Disaster management committees	62
Veterinary officers	49

Note: n, number of respondents interviewed.

Table 14. Community perceptions on key actors for strengthening the implementation of climate change disaster preparedness strategies in Mpigi district.

Key actor	Community perception why consideration as a key actor
Non-governmental organisations	Have resources for implementation of community-development programmes
Farmer's groups	Are close to the community and host individual farmer's membership. They have social capital and are a key entry point for implementation of development programmes and policies
Agricultural and veterinary officers	These are government departments responsible for implementation of government programmes and policies at the local level
Local council	Are constitutionally elected leaders and charged with making legislation, approving local plans and budgets for community development
Radio station	Play a key role of information dissemination and majority of farmers have radios and telephones
Religious institutions	Are closer to the community and have a strong influence on the farmers through their religious doctrines and teachings. Some of them have community-development outreach programmes
Cultural institutions	Are close to the community and have a strong influence on the farmers through culture and customs. They have community-development outreach programmes
Disaster management committees	Play key roles in the implementation of disaster preparedness strategies at district, sub-county and village levels

Source: Synthesised data generated from focus group discussions with selected respondents in the study site.

Tol (2009). However, earlier reports by Pulhin et al. (2006) indicated that vulnerability of each wealth rank varies depending on access to resources and alternative livelihood options.

It was evident that some respondents are engaged in off-farm income-generating activities for survival from the effects of climate change disasters (Table 5). Thus, climate change disasters triggered respondents to engage in off-farm income-generating activities. This is in agreement with earlier arguments by NAPA (2007) and NEMA (2010) that communities engaged in off-farm income-generating activities as a coping mechanism to climate variability impacts.

The respondents' perceptions on key existing actors in the implementation of community-based disaster preparedness strategies (Table 6) was based on the actor's presence in community and the contact with the farmers. Their presence was felt when the actor is implementing routine community-development activities. The contact was through continuous exchange of information with the farmers on various development issues. In this case, it is obvious that the radio station was perceived as a major actor. This is largely because about 97% of the households in Uganda own and listen to radios (Steadman Group, 2009).

Moreover, a large proportion of respondents considered radio station as a key existent actor in the implementation of climate change disasters at community level (Table 6). This showed that radio plays a key role in early warning and early action through dissemination of information about climate variability in the community. The perceptions of males and females were different regarding radio station as key existent implementation actor. This is not surprising, considering earlier reports by Gillwald, Milek, and Stork (2010) that in Uganda men listen to radio more than women, 96% and 78%, respectively.

The higher likelihood of men to consider radio station as a key existing actor in the implementation of community-based disaster preparedness strategies (Table 6) is not surprising. This is attributed to the differentiated gender roles between males and females at the household level. The daily work schedule of rural women is busier and longer with more routine household chores (such as gardening, fetching water and firewood, cooking and taking care of the children) compared to men (DFID, 2008). Consequently, it is assumed that women have less time to listen to radio as compared to men.

Overall, the respondent's perceptions depicted that they were closely working with these actors. Despite this, the study never examined the effectiveness of the actors' activities in addressing climate change disasters. Subsequent studies should evaluate their capacities in this respect.

The lower importance attached to management committees and the meteorological officers as existent actors (Table 6) in the implementation of disaster strategies indicates inadequate implementation of community disaster preparedness strategies by both institutions. The respondents reported that this was largely due to limited capacity in the form of inadequate resources investment. Hence, these committees are not well resourced (in terms of logistics, technical knowledge and skills) to actively implement disaster preparedness strategies, as stipulated in the National Disaster Preparedness and Management Policy (2010). This is in agreement with earlier studies by UNCT-Ug (2011) that disaster preparedness at the community level is still very limited because the lower structures for disaster are not actively functioning in most districts due to technical capacity and resource gaps. Nguyen, Prabhakar, and Shaw (2009) reported similar results, indicating non-implementation of community disaster preparedness plans in Cambodia due to inadequate capacity of local disaster management committees and limited resources to facilitate implementation.

Particularly, in the case of meteorological officer, it depicted poor flow of information on climate variability forecasts to other stakeholders at local and community levels. This is a limitation for timely implementation of early actions by stakeholders at different levels.

Any interventions targeting to strengthen disaster preparedness at the community level should involve these key existing actors, considering that they are already involved in the development activities in the area. The key non-governmental organisations working in the study site were Uphold-Uganda, World Vision, Agro-forestry VI, Buganda Culture and Development Foundation, Voluntary Action for Development and Uganda Christian University Community Outreach.

It is not surprising that a small proportion of the respondents reported that training for disaster management committees in their area was conducted as an early action (Table 7). This is largely due to inadequate implementation of the formal policy disaster preparedness strategies, especially at the village and sub-county levels in most districts including Mpigi. Similar arguments were raised by UNCT-Ug (2011).

The inadequate implementation of the climate change disasters strategies triggered smallholder farmers to implement several early actions as responses to climate change disasters at community and village levels (Tables 8 and 9). For instance, the early actions implemented against prolonged droughts were planting drought-resistant crops, such as cassava, indigenous crops such as arrow roots (*Maranta arundinaceae*) and upland yams (*Dioscorea* spp.).

These actions constituted an informal disaster preparedness initiative at community level responding to climate change disasters in Mpigi district. This is based on indigenous knowledge transferred to farmers through generations, earlier experience and knowledge with climate change disasters over the previous period among farmers. It is anchored by individual farmer's initiative with support from farmers' groups and non-government organisations operating at community level. Earlier studies by Anandaraja, Rathakrishnan, Ramasubramanian, Saravan, and Suganthi (2008), Nguyen et al. (2009), Ogalleh, Christian, and Hauser (2013), Roncoli, Ingram, and Kirshen (2002) highlighted the importance of indigenous knowledge by communities to respond to natural disasters. It is important that this informal community-based disaster preparedness initiative is integrated with the formal initiatives to deliver more benefits through synergies (Makwara, 2013).

Farmers' earlier experience with climate change disasters inform their own early actions at individual level to deal with disasters. Braman et al. (2013) presented similar arguments that Red Cross staff in Togo, took early actions against floods in 2008 because they had learnt from earlier experiences and lessons from floods of 2007.

Therefore, farmers are very resourceful by providing information about occurrence of disasters in their community during development of community-based early warning systems. This conforms to thoughts by Nakashima, Galloway McLean, Thulstrup, Ramos Castillo, and Rubis (2012) that indigenous knowledge could offer useful insights about climate change, and complement scientific research with local experiences. Similar arguments were raised by Mutua (2011) that communities have traditional ways and institutions for handling disasters, including early warning systems and environmental management. But these practices and institutions are not recognised by development facilitators and subsequently development initiatives exclude their experiences and lessons.

The key challenges perceived by respondents (Table 10) make implementation of community disaster preparedness strategies less effective. Subsequently, in most cases when the disasters strike there is limited immediate support for the community members affected. Consequently, emergency response remains as the only option to support affected communities. Some of the earlier cases reported in this respect were Uganda Red Cross Society that donated food aid to flood victims in Mpigi district (Africa News Service, 2003); 492 people in Mpigi district needed emergency support due to effects of hailstorms that destroyed their houses, crops and livestock (Uganda Red Cross Society, 2011).

The key opportunities as perceived by the respondents (Table 11) should be harnessed to strengthen the disaster preparedness in the district. A low proportion of the respondents considered existence of disaster management committees as key opportunity for strengthening community preparedness for climate change disasters. This was expected because a large proportion of respondents perceived disaster management committees as non-existent actors in the implementation of disaster strategies (Table 6).

The key actions highlighted by the respondents would indeed strengthen the implementation of climate change disaster preparedness strategies at the community level. This is logical because these actions address the key challenges for implementation of disaster strategies (Table 10).

All stakeholders whether percieved as existent or non-existent should be involved in the implementation of the community climate change disaster preparedness strategies. Each of the stakeholders has varying capacity and roles to play in the implementation. According to Kapucu (2008), good coordination and interaction among all stakeholders would result in effective implementation of the disaster preparedness strategies.

The National Disaster Preparedness and Management Policy (2010) (Table 2) never included religious and cultural institutions among key stakeholders for implementation of the policy. This was an oversight considering that respondents perceived these institutions as key actors in the implementation of climate change disaster strategies at community level. Wisner (2010) had similar argument that all over the world faith communities were already active in disaster preparedness activities. They are among the fast responders and providers of immediate assistance. Therefore, implementation of disaster preparedness policy strategies at all levels should consider active involvement of these institutions.

We draw the following summary in light of the study objectives that aimed at establishing farmers' perceptions of implementation of climate change disaster preparedness policy strategies and identification of existing community early actions against climate change disasters:

(1) Farmers perceived prolonged droughts, increased pests and diseases outbreaks due to climate variability as the major climate change disasters in Mpigi district. These disasters

triggered farmers' engagement in off-farm income-generating activities as a coping mechanism against climate change disasters impacts.
(2) Everybody is affected by climate change disasters regardless of their wealth status.
(3) Farmers considered implementation of climate change disaster strategies at community level in Mpigi district as inadequate. They attributed this to lack of climate change disasters forecast; lack of logistics and funds for disaster preparedness and lack of community early warning action plans as the major challenges for implementation of community climate change disaster preparedness strategies. However, the inadequate implementation of climate change disaster strategies triggered various early actions by farmers as responses to climate change disasters. Therefore, farmers are active victims of climate change disasters. The key early actions implemented against climate change disasters included: planting drought-resistant crops and construction of soil- and water-conservation trenches on farms.
(4) Males are highly likely to consider radio stations as key existing implementation stakeholders compared to women.

5. Conclusions

Based on the study results, we conclude that effective implementation of disaster preparedness strategies is needed to avert the current negative climate change disasters impacts on community livelihood. Farmer's early actions for addressing climate change disasters should be integrated in the implementation of the climate change disaster policy strategies at household, village and sub-county levels in Mpigi district. The use of the radio for awareness during the implementation of the climate change disaster preparedness strategies is highly likely to reach out for the benefit of males. Therefore, alternative approaches for reaching out to women in the implementation of these strategies should be designed.

Further research studies should focus on enhancing capacity of existing actors by evaluating their strength, weakness, opportunities and threats in the implementation of climate change disasters preparedness strategies. The effectiveness of their climate change disasters management activities at community level should be examined. Furthermore, strengthening of climate change disaster safety nets based on off-farm income-generating activities should be explored.

The Office of the Prime Minister – Department of Relief, Disaster Preparedness and Management – should expedite the implementation of climate change disaster strategies at community level. It should build on existing actions, knowledge and capacities of the stakeholders in the community.

The capacity of disaster management structures at the district, sub-county and village levels should be adequately resourced and trained for effective implementation of disaster preparedness strategies.

Information dissemination about climate change disasters and related early actions by various stakeholders at different levels should be strengthened. Available means including radio stations, community, religious and cultural events should be used.

6. Disclaimer

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Paper II

Climate Variability triggers Innovations for Adaptation and Mitigation; A case for Smallholder Banana Farmers in Central Uganda.

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Climate Variability triggers Innovations for Adaptation and Mitigation: A case for Smallholder Banana Farmers in Central Uganda

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Abstract
This paper evaluates smallholder farmers' innovations for climate change adaptation and mitigation using smallholder banana farmers in Central Uganda as a case study. Furthermore, synthesis was done focusing on the existing stakeholders facilitating innovation development, the key challenges and associated recommended strategies for advancing long-term adaptation and mitigation of climate change through contributions by farmer innovators were studied. Data were collected through semi-structured household interviews and administration of key informant checklists involving key stakeholders at community and national levels. Using the Statistical Package for Social Sciences 16, data obtained through semi-structured interviews were subjected to quantitative analysis to generate percentages for several variables and cross-tabulation analyses between selected variables. Data generated from expert interviews were synthesized through content analyses. Climate change impacts triggered the development of innovations for adaptation and mitigation by smallholder banana farmers. Despite this, farmer innovators are faced with key challenges limiting their further development. These must be addressed to contribute to long term adaptation and mitigation of climate change impacts at farm level.

Key words: climate change impacts; adaptation; mitigation; Eastern Africa.

1. Introduction

It is projected that climate change will significantly impact negatively on agriculture in Uganda like many other Countries in Sub-Saharan Africa. According to the National Adaptation Program of Action on Climate Change in Uganda [NAPA] (2007), some of the reported climate change disasters in Uganda include: prolonged droughts, unreliable rainfall patterns, heavy rains with hailstones, heavy rains with strong winds, floods. The major impacts associated with these disasters are: food insecurity and hunger due to reductions in crop yields as a result of water scarcity, water logging and destruction by altered insect pest population and species. Thus, it is predicted that agricultural productivity will fall by up to 30% over the 21st century (Intergovernmental Panel on Climate Change [IPCC], 2001); Reduction in gross domestic product contribution by agriculture from 21 to as little as 4% by 2100 (Mendelsohn, 2000). The poorest countries would be hardest hit (IPCC, 2001). Their smallholder farmers with the least adaptive capacity are the most vulnerable to climate change impacts (Morton, 2007).

However, smallholder farmers are not passive victims of climate change impacts, they are trying out various actions and practices for adaptation and mitigation against the impacts (Adger et al., 2003). Their techniques, actions and practices depending on the level of development in respect to the innovation's definition, constitute a climate change smallholder farmer's innovation system for adaption and mitigation at farm and community level.

According to Pol (2009), innovations constitute new ideas with potential to improve either the macro-quality of life or the quality of life at a significant scale. They comprise of changes to the past situation resulting in the introduction of something new. Innovations have technical, social, organizational, managerial, institutional or political dimensions. They are creations of social and economic significance that may be brand new but more often combinations of existing elements. Innovation can be a product or an activity within a process. They could be incremental or radical; exogenous or endogenous or both, thus mixed innovations; positive or negative given the perspective; and can be scaled up and out from the point of origin (Hauser et al., 2011). Promoting Local Innovation in Ecologically oriented Agriculture and Natural Resource Management [PROLINNOVA] (2004) and the World Bank (2004) define farmer innovation as the dynamics of indigenous knowledge developing within a social group based on learning from own experience over generations and external knowledge internalized within the local ways of thinking and doing.

Hall (2006) and Assefa et al. (2009) defined innovation system as a network of organizations and individuals focusing on the connection of products, processes and types of organization into economic use together with the policy frameworks effecting their behavior and performance. This concept embraces both the science suppliers and all actors involved in the innovation. He noted that innovation processes can be triggered in many ways such as barriers in production, changes in existing technology and competition (Hall, 2006).

In this respect, several farmer innovations in agriculture and natural resources management particularly on aspects of soil and water conservation, land management, livestock management, and bio-pesticides among others have been evaluated and documented (Chrichley et al., 1999; Reij and Water-Bayer, 2001; and Duveskog et al., 2002). Despite this, smallholder farmer innovators are limited by various challenges to advance the growth and development of their innovations. In this respect, Fenta and Assefa (2009) noted that in most cases farmer innovations can be invisible unless time is taken for discussion and probing with them in a learning spirit and process. Sanginga et al. (2009) argued that they are also characterized by the weak linkage between farmer innovators, public research, development organizations and private sector.

Furthermore, the United Nations Framework Convention on Climate Change [UNFCCC] (2008) highlighted the key challenges for implementation of farmers' management practices as being cultural and social (particularly education and information gaps, incompatibility with traditional local practices) and lack of appropriate incentives.

However, innovations for climate change adaptation and mitigation by smallholder farmers have not been identified, evaluated and documented in Uganda (NAPA, 2007, PROLINNOVA, 2011 and Ajani et al., 2013). Subsequently, this knowledge is not integrated into policy and program implementation for long-term adaptation and mitigation to climate change (Pandey, 2006 and Osman-Elasha, 2007). Furthermore, the farmer innovators receive limited supported for advancing their innovations (PROLINNOVA, 2011). These innovations contribute to longterm climate change adaptation and mitigation in smallholder farming systems (Ajani et al., 2013). The case study results help to further understand farmer innovations for climate change adaptation and mitigation. This is useful for the formulation of practical recommendations to advance the development of farmer innovations for climate change adapation and mitigation. Thereby contributing to long-term resilience to climate change impacts at the community level.

The study was informed by the conceptual framework based on adjustments of the theoretical framework according to Smit et al. (1999) called, *'engine of adaptation science.'* It is assumed that due to impacts of climate variability induced disasters such as unreliable rainfall patterns, prolonged droughts, floods, strong winds, and hailstorms, farmer innovators test new ideas and or make adjustments in existing common agronomic techniques and practices as responses for climate change adaptation and mitigation through an innovation system. Based on reports by Hocdé et al. (2006), the innovation system is supported by several stakeholders including research and development organizations such as Farmers groups, Government Agricultural Extension, Non-Government Organizations, Community-based Organizations, Private Sectors, and Research Institutions. These stakeholders have varied knowledge, attitudes, beliefs, interests and play different roles for advancement of adaptation and mitigation to climate change impacts in the smallholder banana farming systems (IPCC, 2007).

The study tested the hypothesis that climate variability greatly impacts on the livelihood of smallholder banana farmers in Central Uganda. As a result, they try out various actions and practices for climate change adaptation and mitigation, which depending on the definition constitute farmer innovations. It targeted to answer the following research questions: What are the farmer's perceptions of the current climate conditions in the study area? Do climate variability conditions trigger farmer innovations for adaptation and mitigation? What are the key challenges limiting farmer innovation development? Who are the key stakeholders supporting the innovation development process at farm level? What are the recommendations for promoting farmer innovations for climate change adaptation and mitigation?

Therefore, this study evaluated smallholder farmers' innovations for climate change adaptation and mitigation in banana-coffee robusta (*Musa species-coffee cenephora*) farming systems in Central Uganda. Furthermore, to understand the existing stakeholders facilitating the innovation development process and identification of the key challenges and associated recommendations for advancing farmer innovations as contribution to long term adaptation and mitigation of climate change.

2. Materials and methods

2.1 Overview of the study site

The study was carried out in Mpigi district, Central Uganda. The district land area is 3715 square km. The distribution of the district land area is as follows: 719 square km is covered by water and wetlands; 1025 square km is arable land with approximately 38% covered by crops, and approximately 1100 square km covered by forests (National Environment Management Authority [NEMA], 2010). The district relief is generally comprises of plateau and small undulating hills. The hill summits have an average altitude of 1262 meters above sea level.

Mpigi district has two rainfall seasons. The first season occurs in the period of March-May whereas the second occurs during September-November annually. It receives a mean annual rainfall of 1320 mm and on average 10 days of rainfall per month. The minimum temperature of the district is 11^{o} C. On the other hand, the maximum temperature is 33^{o} C. However, climate variability manifesting as various forms of disasters (such as prolonged droughts spells, heavy rains, hailstorms that cause destruction of plantations increasing the risks of food shortages in many households) is a major challenge to agricultural production in the area (NEMA, 2010).

According to the Uganda Bureau of Statistics (2011), the average population growth rate of Mpigi district over the last decade is 3% with a population density of 230 people per square km. Thus, its population density is 1.4 times greater than the national average.

The major land use in Mpigi district is subsistence agriculture with crop farming and animal husbandry as key enterprises. The district is located in the Banana-coffee agro-ecological zone whose climate and soils support production of Banana and Coffee (Ministry of Agriculture, Animal Industries and Fisheries, 1995a). Most of the farmers in the district are smallholders with an average land holding of 0.8 hectares. Bananas, coffee, cassava, sweat potatoes are some of the crops cultivated in the district. The major food crop is bananas. According to NEMA (2010), it is also an important cash crop among others including coffee and horticultural crops especially tomatoes [*Solanum lycopersicum*], vanilla [*Vanilla Planifolia*], and pepper [*Capsicum Spp*.].

Mpigi district was selected as the study site because it is already affected by climate change disasters that greatly impact on livelihoods of smallholder banana-coffee farming communities. In Mpigi district, it was carried out in two sub-counties (Nkozi and Kituntu) which were selected during an inception meeting which involved key stakeholders. The stakeholders comprised of district and sub-county political officials from several sectors including production, environment and community development. The stakeholders clearly pointed out that Nkozi and Kituntu are most affected by climate change disasters as compared to other sub-counties in the district and hence this was the basis for their selection. Hence, both sub-counties combined constituted the study site. In Figure 1 the location of the study site is illustrated.

2.2 Sampling design

Respondents who participated in the household survey were selected randomly using existing lists of official registered farmers' groups at sub-county level. Semi-structured questionnaires were used for data collection. They were pre-tested before administering them among 133 smallholder farm households. 3 Farmer innovators were probed further and this involved using check lists with key questions designed based on the innovation assessment frame work (Pant, 2010) to understand their innovations better. The purpose of this was to examine the innovation systems with a particular focus on why the farmer developed the innovation? How it is done. Whether it is effective? Who are the key stakeholders supporting the farmer innovators? What challenges do they face in the innovation process?

Rainfall data for the last 15 years (i.e. for the period 1998-2012) was collected from Madu meteorological station in Mpigi district (Tropical Rainfall Measuring Mission Data, 2013).

Key informant interviews were conducted using key informant check lists to generate feedback from 30 selected key stakeholders at national and local levels about key challenges and strategies for addressing them with support for farmer innovations development for climate change adaptation and mitigation. The key stakeholders were selected from the following institutions: Ministry of Agriculture, Animal Industries and Fisheries, Climate Change Unit under the Ministry of Water and Environment, Non-government Organizations, Private Sector, National Agricultural Research Institute, Development Partners, Mpigi district Local Government representatives and Uganda National Farmers Federation. They were selected purposively with consideration that they are involved in policy implementation and that climate variability impacts present key challenges for effective implementation of their work.

2.3 Data analysis

The Statistical Package for Social Sciences version 16 was used to analyze data obtained using semi-structured questionnaires administered during the household survey. The analyses focused on generation of percentages of several variables and determination of existence of relationship between selected variables using the Pearson chi square tests based on Asymp. Sig. (2-sided) at 5%.

The rainfall data collected were used to understand the rainfall trends using simple graphing techniques by plotting rainfall quantities against the time scale and fitting the trend lines using curve fitting techniques in micro-soft excel.

The information generated from the farmer innovators and other actors were used to describe the farmer's innovations for climate change adaptation and mitigation. The key challenges the innovation development process and the suggested strategies for addressing them identified through interviews with key informants were synthesized through content analyses.

3. Results

3.1 Farmers' perceptions of current climate conditions

Data in Table 1 show respondents' perceptions of the current climate conditions in Mpigi district. The perceptions of males and females were comparable.

In Table 2, the reasons for respondents' perceptions of the current climate conditions of Mpigi district are depicted. Likewise, the perceptions of both males and females are comparable.

Respondents perceived increased daily temperatures (95%), wind speed (94%), occurrence of prolonged droughts (81%) and increased scotching sun (36%) as the major changes in climate conditions in the study area over the last 10 years.

3.2 Trends analyses – climate variability (particularly rainfall variation over a period of 15 years)

Figure 2 depicts a downward trend for the linear mean monthly rainfall received in Mpigi district over the last 15 years. The highest mean monthly rainfall was received in 2001 were as the lowest was received in 1998.

Data in Figure 3 show that the number of dry season days in Mpigi district sharply decreased during the period 1998-2006. They gradually increased during the period 2007-2012. The number of dry season days was highest in 2000 and least in 2006.

Likewise, the number of rain season days over the last 15 years follows an upward trend (Figure 4). The highest number of rain days occurred in 2006 and least in 1998.

3.3 Farmer's Perceptions of climate change implications

Data in Table 3 show respondents' perceptions of climate change impacts on livelihood in Mpigi district. They perceive increased frequency of hunger and increased incidence of climate related diseases in humans, crops and livestock as the key impacts on livelihood. The major crop diseases for major crops (banana-coffee) on the farms as perceived by the respondents were banana wilt [*Xanthomonas*] (96%); coffee wilt [*Tracheomycosis*] (85%); coffee stem borer [*Xylotrechus javanicus*] (50%); banana weevil [*Cosmopolites sordidus*] (35%); coffee leaf rust [*Hemileia vastatrix*] (26%). On the other hand, the major livestock diseases on the farms as perceived by the respondents were worms (78%); African swine fever (54%); Newcastle [*Paramyxovirus-1*] (25%); East coast fever [*Theileria parva* infection] (36%); and Pneumonia (20%).

3.4 Existing climate change adaptation and mitigation practices and innovations at farm level

Data in Table 4 show that respondents perceived practicing agroforestry on-farm; membership in a farmer's group to obtain support (i.e. credit and social capital) and planting arrow roots *(Maranta arundinaceae)* and drought resistant crops as the major climate change adaptation and mitigation practices.

3.5 Existing innovations for climate change adaptation and mitigation

The relationship between respondents' perceptions of current climate conditions and development of innovations for adaptation and mitigation of climate change impacts is significant at 5%. Thus, the respondents who perceive the current climate conditions as bad and very bad are 1.5 and 1.0 times more likely to create shade for young coffee plants using Kisansa (*Phoenix reclinata*) branches as an adaptation innovation against prolonged droughts (Table 5). A similar behaviour is observed in the case of controlling and management of banana weevils in the banana plantation. Hence, the respondents who perceive the current climate conditions as bad and very bad are 0.5 and 0.8 times more likely to intercrop hot pepper (*Capsicum sp.*) in their banana plantations for management of banana weevils (Table 6). Likewise, the respondents who perceive the current climate conditions as bad and very bad are 0.2 and 0.4 times more likely to apply manure in rectangular holes established between 4 banana/coffee trees and covering it with soil and banana leaves as an adaptation and mitigation innovation to climate change impacts (Table 7).

3.6 Description of identified key farmer innovations for climate change adaptation and mitigation in the study site

Data in Table 8 show the description of key identified farmer innovations for climate change adaptation and mitigation in the study site. All the innovations identified are technical innovations based on agronomic practices for banana and coffee production.

3.7 Major challenges limiting farmer innovations development process for climate change adaptation and mitigation

Table 9 shows the synthesized perceptions of key informants regarding major challenges limiting farmer innovations development for climate change adaptation and mitigation in the study site.

4. Discussions

The respondents' perceptions of the current climate conditions in Mpigi district, Central Uganda (Table 1) as attributed to reasons in Table 2 are in agreement with earlier reports in Uganda (NAPA, 2007). Some of the respondents' perceptions of the climate change in the study area over the last 15 years concur with recorded climate data from the nearest Madu meteorological station over the same period. In this case, the perceived occurrence of prolonged droughts as the change in climate conditions over the last 15 years is not by surprise considering that the observed climate data for the area show that there was a downward trend for the mean linear monthly rainfall received (Figure 2); and the number of dry season days have increased (Figure 3). Similar concurrence between farmers' perceptions of climate change and observed climate data from meteorological station was earlier reported by Ogalleh et al. (2013) for farmers in Laikipia district in Kenya. Likewise Manandhar et al (2011) reported that farmers' perceptions of climate change conditions in Nepal indicated that the length of cold waves has increased over the last 14 years (i.e. 1992-2006) were in agreement with climate data from meteorological stations over the same period.

The impacts of climate change on livelihood as perceived by the respondents are expected (Table 3) because the current climate change conditions in the study area directly cause the impacts (Table 1). For instance, prolonged droughts cause poor crop and livestock productivity resulting into food insecurity and hunger thereby exacerbating household poverty (Lundquist and Falkenmark, 2010). Similarly, the increased scotching sun and daily temperatures directly influence the micro-climate for certain pests and diseases pathogens in crops, livestock and humans (NAPA, 2007; Agricultural Sector Development Strategy and Investment Plan [DSIP], 2010 and the National Policy on Disaster Preparedness and Management, 2010).

The observed respondents' perceptions regarding existing climate change adaptation and mitigation practices at farm level in the study area (Table 4) clearly show that smallholder farmers are not passive victims of climate change disasters. Adger et al. (2003) reported similar arguments. Indeed, earlier reports by Mortimore (1998) indicated that pastoralists in the West African Sahel have adapted to rainfall reductions of 25% - 33% in the twentieth century. Furthermore, resilience in the face of changing climate was documented for smallholder farmers in Bangladesh and indigenous hunting communities in the Canadian Arctic by Huq (2001) and Berkes and Jolly (2001), respectively. Also Kansiime (2012), reported that communities in Eastern Uganda have innovative coping mechanisms for climate change which are based on past experience, local knowledge and expertise.

Besides the existing common climate change adaptation and mitigation practices (Table 5), there is evidence that climate change conditions have triggered farmer innovators to move a step further by developing innovations for adaptation and mitigation (Tables 5, 6 and 7). Similar arguments were reported by Low-External-Input and Sustainable Agriculture [LEISA] (2001) that traditional farmers have developed numerous indigenous farming systems adapted to several aspects of their environment (including climate change) through innovation processes.

The 3 cases of farmer innovations for climate change adaptation and mitigation which were identified and described (Table 8) all have the following in common:

(i) In all cases the innovators are members in a farmer's group. This provides opportunity of sharing and dissemination of the innovations among other farmers through farmer to farmer extension. Leitgeb et al. (2011) raised similar reports regarding the importance of the farmer to farmer movement for knowledge exchange and diffusion of innovations among farmers in Cuba;

(ii) They are all technical innovations which meet the key requirements of the TEES test (i.e. technically effective, economically valid, environmentally friendly and socially acceptable) according to Critchley et al. (2007) as illustrated in Table 10. Thus, the innovations are sustainable considering that they result into positive economic benefits without negative environment, social and cultural implications;
(iii) For each case the innovation's support system is more or less similar. Particularly, it comprises of the farmer innovator, farmers' group, extension services and non-governmental organizations. This is expected because the farmer innovators are from the same locality and therefore exposed to similar challenges and opportunities;
(iv) In all the cases, the innovation has diffused from the farmer innovators to other farmers in the village. This is possible because the farmer innovators are not working in isolation. Thus, they belong to farmer's groups which are entry points for development initiatives but also platforms for information exchange, training and learning at the village and community level;
(v) For each case the innovation has benefits to the users. Despite this, in the context of climate adaptation and mitigation, these innovations are not an independent solution. Thus, the impact of these farmer innovations would further require augmentation by implementing broader climate change adaptation and mitigation strategies at the farm and community level (Bruno et al., 2009 and Below et al., 2010). In Uganda, such strategies include the following as stipulated in the NAPA (2007) and DSIP (2010): increasing access to appropriate irrigation technologies such as water pumps; growing of drought resistant and early maturing crop varieties; reduction on taxes charged on agricultural chemicals for farmers to afford herbicides for treatment of pests and diseases.

However, the advancement of innovations for climate change adaptation and mitigation is limited by several challenges (UNFCCC, 2008 and Sanginga et al., 2009). Some of the major challenges as perceived by key informants (Table 9) are similar to those reported by Sanginga et al. (2009), particularly the weak linkage between farmer innovators and other development players including public research and development organizations and private sector. Furthermore, Kansiime (2012) reported that were as there are initiatives to support community adaptation to climate change in Eastern Uganda, they existed in an adhoc manner.

The strategies suggested by the key informants for addressing these challenges can be implemented through integration in the following ongoing initiatives at national and local levels: Advancing policy formulation and implementation – particularly the National Climate Change Policy and the National Agricultural Policy; Programs implementation at national and local levels – such as the Agricultural Sector Development Strategy and Investment Plan, National Agricultural Extension, National Agricultural Research Systems, and Local Government Development Program. Furthermore, farmer innovations for climate change adaptation and mitigation can also be supported through the farmer managed innovation grants such as the Local Innovations Support Funds promoted by Non-Governmental Organization-led initiatives such as PROLINNOVA (Ton et al., 2015) implemented in Nepal, Cambodia, Ethiopia, South Africa and Uganda.

5. Conclusions

This article describes the farmer's innovations for adaptation and mitigation of climate change impacts. The case of Central Uganda clearly shows that smallholder farmer's perceptions of climate change conditions were in agreement with the observed climate change as depicted by meteorological data for the study area over a period of 15 years. However, farmers are not passive victims of climate change. They are implementing several common agronomic practices, technologies and actions to adapt and mitigate climate change impacts. Furthermore, the observed negative climate change conditions in the study area triggers smallholder farmers to develop new ideas or changes in existing common practices based on their knowledge and earlier experiences. These new ideas and or changes in existing common agronomic practices described as farmer innovations are beneficial as they are practical solutions to advance adaptation and mitigation of climate change impacts at farm level.

It is important to recognize that farmer innovators are continuously working in the face of the impacts of climate change disasters to develop innovations for adaptation and mitigation. Therefore, more farmer innovations should be identified, evaluated and supported.

Smallholder farmers' perceptions based on their knowledge and earlier experience about climate change should never be under estimated as a source of information for policy and program implementation. Hence, such information should be used for informed decisions making during implementation of development programs at community level. For cases where specific and localized meteorological data are not available, such information from farmers can be used as a key reference for early decision making for policy and program implementation;

The challenges limiting the climate change innovation development process by smallholder farmers should be addressed to strengthen their capacity for climate change adaptation and mitigation at farm level. The suggested strategies for addressing these challenges are presented in Table 9.

However, further research should focus on carrying out joint experimentation through participatory approaches with farmers and other key stakeholders in the innovation system at farm and community levels. This should be done with an overall aim of adding value to farmer innovations through validation, documentation and dissemination. Furthermore to understand the social-economic benefits of the farmer innovations for adaptation and mitigation of climate change impacts.

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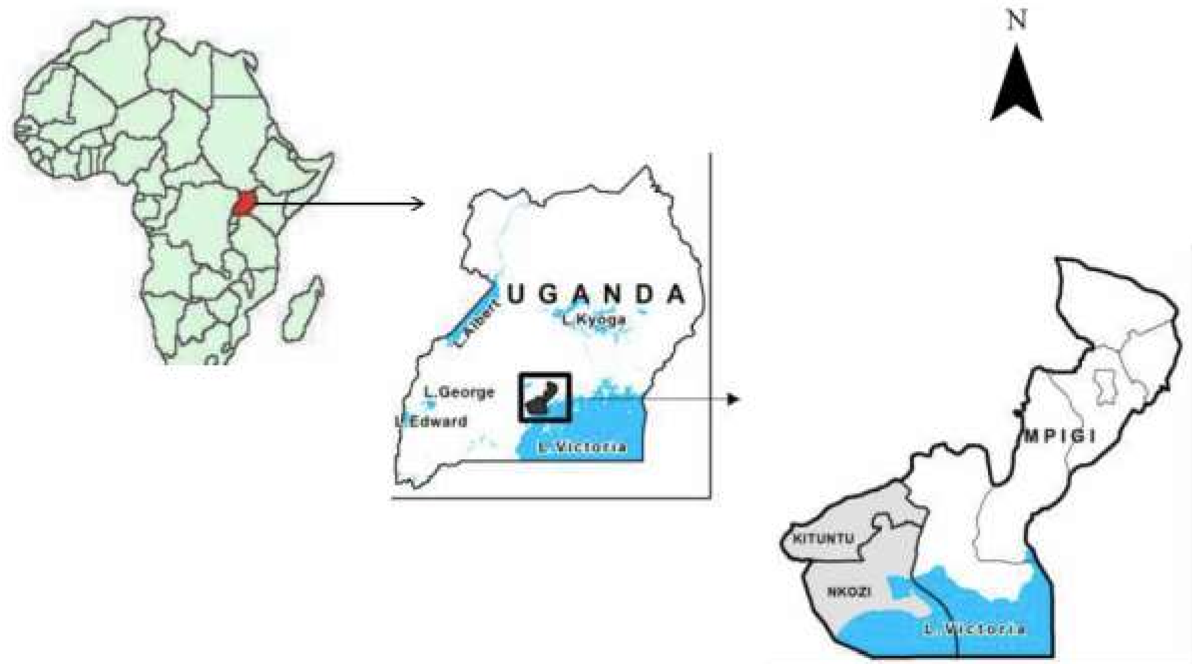

Coordinates for Mpigi district: 00^{0} 14'N 32^{0}20'E

Derived from Google images (Accessed 17 May 2014.

Figure 1 Location of study site.

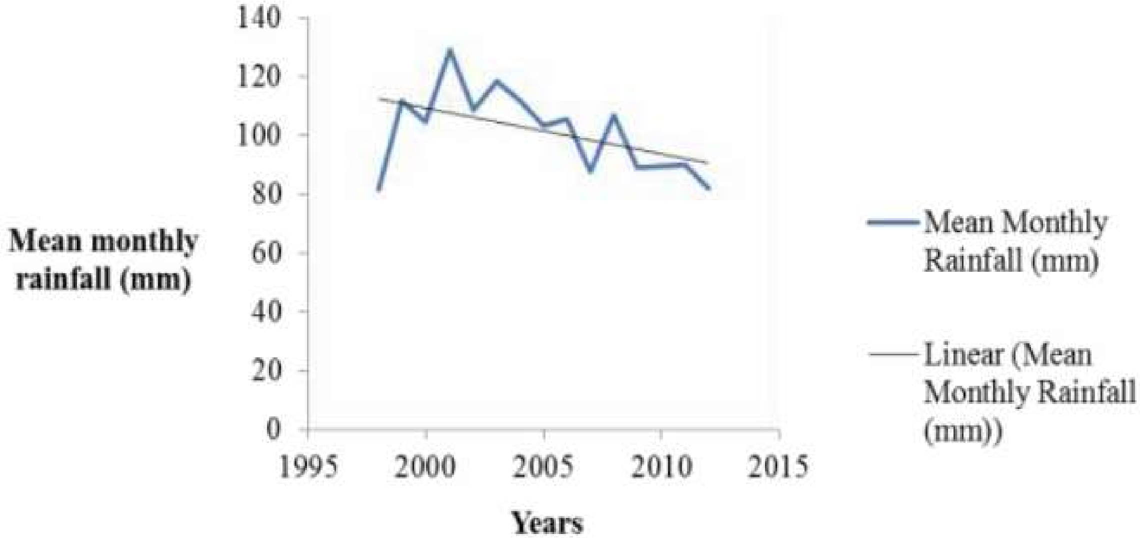

Figure 2 Mean monthly rainfall in study area over 15 years (1995-2012)
Source: Madu meteorological station in Mpigi district, Central Uganda. Tropical Rainfall Measuring Mission Data 2013.

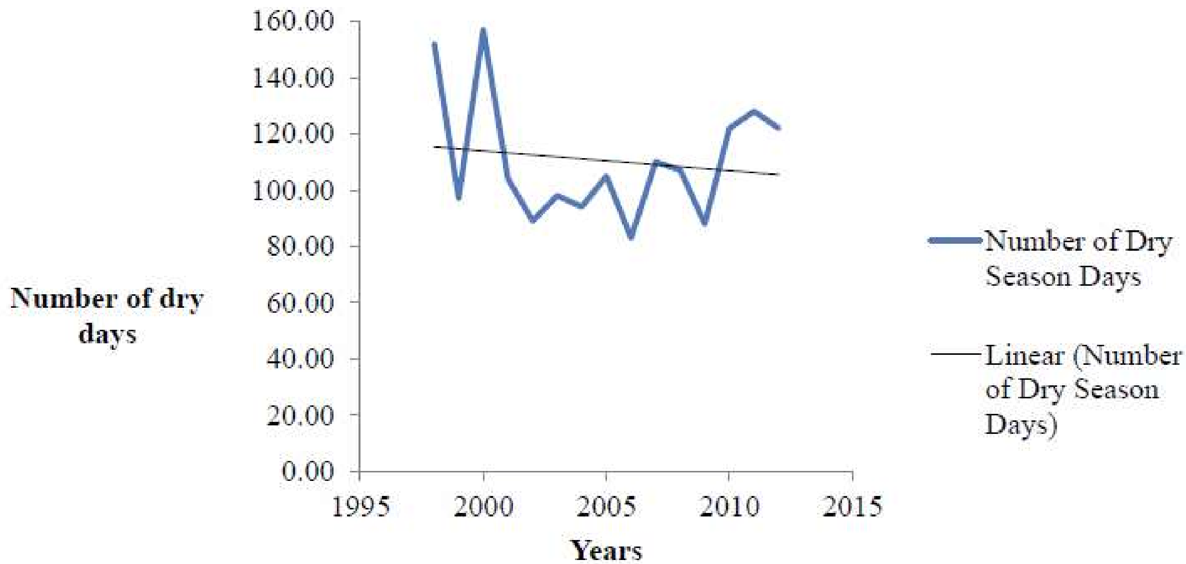

Figure 3 Number of dry days during the dry season in study area over 15 years (1995-2012).
Source: Madu meteorological station in Mpigi district, Central Uganda. Tropical Rainfall Measuring Mission Data 2013.

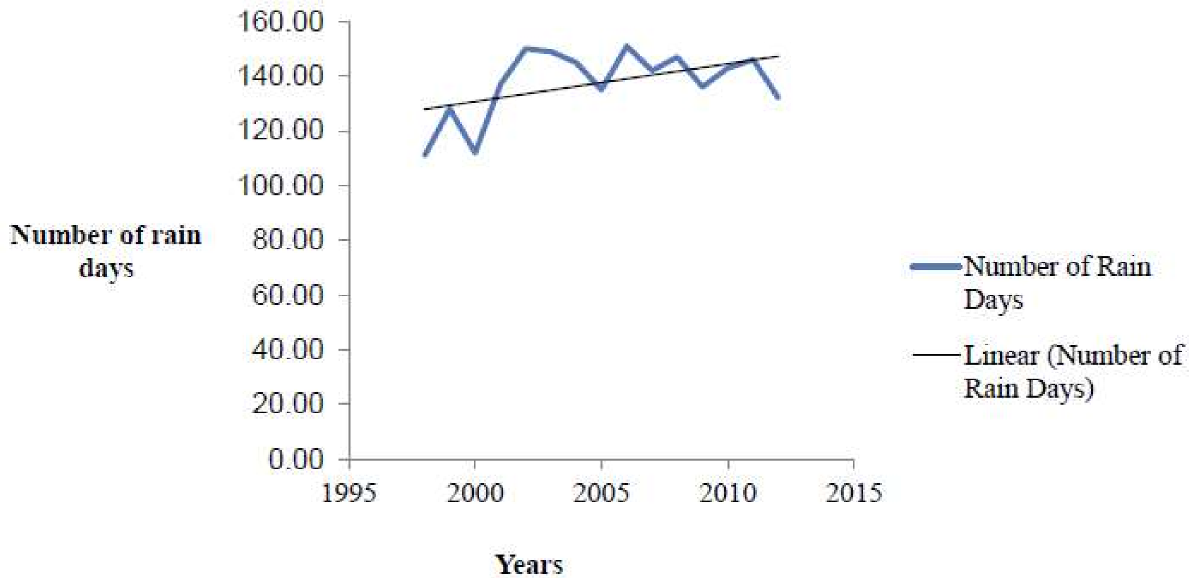

Figure 4 Number of rain days during the rainy season in the study area over 15 years (1995-2012).
Source: Madu meteorological station in Mpigi district, Central Uganda. Tropical Rainfall Measuring Mission Data 2013.

Figure 5 Left photo – shows the Oluwannyi (*Draceana fragrans)* plant whose stems and leaves were initially used for shading the young coffee seedlings; Middle photo – shows the stems and leaves of Kisansa *(Phoenix reclinata)* plant currently used for shading young coffee (coffee cenephora) seedlings; Right photo – shows several coffee seedlings protected from prolonged drought.

Figure 6 Modifications in manure application method in smallholder banana (*Musa spp.*) and coffee (*Coffee cenephora*) plantations in Mpigi district, Central Uganda by Buzimba Francis, a farmer innovator.

Figure 7 Buzimba Francis, farmer innovator using hot pepper (*Capsicum sp.*) for controlling banana weevil borers (*Cosmopolites sordidus*) in smallholder banana (*Musa spp.*) plantation in Mpigi district, Central Uganda.

Table 1 Respondents' perceptions of the current climate conditions in Mpigi district, Central Uganda (N=133).

Current status of climate	Yes		N	df	Pearson chi-square value	p
	Male (%)	Female (%)				
Good	0.8	0	1	3	3.4	0.33
Bad	47	19	89	3	3.4	0.33
Very bad	24	8	42	3	3.4	0.33
I do not know	0	0.8	1	3	3.4	0.33

N = Total number of respondents interviewed; n = Number of respondents who perception is yes; df = degrees of freedom; p = Asymp. Sig. (2 sided) at 5%; * = the relationship between the two variables is significant.

Table 2 Reasons for respondents' perceptions of the current climate conditions in Mpigi district, Central Uganda (N=133).

Reason	Yes		n	df	Pearson chi-square value	p
	Male (%)	Female (%)				
Unreliable rainfall	35	18	64	4	2.4	0.66
Prolonged droughts	19	9	34	4	2.4	0.66
Now it is one rainy season instead of two	5	0	5	4	2.4	0.66

N = Total number of respondents interviewed; n = Number of respondents who perception is yes; df = degrees of freedom; p = Asymp. Sig. (2 sided) at 5%; * = the relationship between the two variables is significant.

Table 3 Respondents' perceived climate change impacts on livelihood in Mpigi district, Central Uganda (=133).

Perceived climate change impacts on livelihood	Yes (%)	
	Increased	Constant
Frequency of hunger	99	1
Incidence of climate related human diseases	98	2
Incidence of climate related crop diseases	98	2
Incidence of climate related livestock diseases	94	6

n = Number of respondents.

Table 4 Respondents' perceptions of existing climate change adaptation and mitigation practices and innovations at farm level in Mpigi district, Central Uganda (n=133).

Existing climate change adaptation and mitigation practices and innovations at farm level	**Yes (%)**
Practicing agro-forestry on-farm	99
Membership in a farmer's group to obtain support (credit and social capital)	95
Planting arrow roots and drought resistant crops	62
Soil and water conservation trenches	56
Creating shade for young coffee (*coffee cenephora*) trees during the dry season	53
Mulching of banana (*Musa spp*.) -coffee plantations	45
Cutting banana pseudo stems around coffee trees to create mulch	39
Irrigation of crops during the prolonged droughts	28

n = Number of respondents.

Table 5 Respondent's perceptions of current climate conditions vs. Creating shade for young coffee plants using Kisansa (*Phoenix reclinata*) branches as adaptation innovation to protect them from prolonged droughts in Mpigi district, Central Uganda (N = 133).

How is the climate currently	**Creating shade for young coffee plants using Kisansa branches as adaptation to protect them from prolonged droughts**		**N**	**df**	**Pearson chi-square value**	**p**
	Yes (%)	No (%)			2.34	< 0.01*
Good	0	100	01	8		
Bad	56	44	89	8		
Very bad	50	50	42	8		
I do not know	0	100	01	8		

n = Number of respondents; df = degrees of freedom; p = Asymp. Sig. (2 sided) at 5%; * = the relationship between the two variables is significant.

Table 6 Respondent's perceptions of current climate vs. Control and management of banana weevil borers *(Cosmopolites sordidus)* using hot pepper (*Capsicum sp.*) intercropped in the plantations as the climate change adaptation innovation in Mpigi district, Central Uganda (N = 133).

How is the climate currently	**Control and management of banana weevils using hot pepper intercropped in the plantations**		**N**	**df**	**Pearson chi-square value**	**p**
	Yes (%)	No (%)			2.34	< 0.01*
Good	100	0	01	8		
Bad	37	63	89	8		
Very bad	43	57	42	8		
I do not know	0	100	01	8		

n = Number of respondents; df = degrees of freedom; p = Asymp. Sig. (2 sided) at 5%; * = the relationship between the two variables is significant.

Table 7 Respondent's perceptions of current climate vs. Manure application in holes established between 4 banana or coffee trees and covering it with soil and banana leaves as the adaptation innovation to prolonged droughts in Mpigi district, Central Uganda (N = 133).

How is the climate currently	**Applying manure in rectangular holes established between 4 banana/coffee trees and covering it with soil and banana leaves**		**N**	**df**	**Pearson chi-square value**	**p**
	Yes (%)	No (%)			2.32	< 0.01*
Good	0	100	01	8		
Bad	19	81	89	8		
Very bad	26	74	42	8		
I do not know	0	100	01	8		

n = Number of respondents; df = degrees of freedom; p = Asymp. Sig. (2 sided) at 5%; * = the relationship between the two variables is significant; banana = *Musa spp*.; Coffee = *coffee cenephora.*

Table 8 Description of innovations for climate change adaptation and mitigation identified in Mpigi district, Central Uganda.

Climate change disaster impact description	Farmer innovation	Description of the innovation	Key observations about the innovation system
Prolonged droughts of 4-5 months in the district result in wilting and death of young coffee seedlings. Consequently, this greatly affects long term productivity and income from coffee (*coffee cenephora).*	Creating shade for young planted coffee seedlings locally known as *okuwembela*. A farmer innovator, Ssekindi William a member of Bukemba Balikyewunya Cooperative Society's Group learnt this practice from his parents in 1970. He later altered it and has practiced it for over 15 years. (See Figure 5).	William's parents used to cut three stems of a plant called Oluwannyi *(Draceana fragrans)* at a height of 30 cm and placed 15 cm side by side each coffee seedling. The stems and leaves create shade for the young coffee seedlings. However, later on he realized that this type of plant stems develop roots which compete for water and nutrients, thus affecting the growth of the coffee seedlings. Instead of using *Oluwannyi,* now he uses stems and leaves of another plant called Kisansa (*Phoenix reclinata*). The branches of this plant do not develop roots and therefore does not competition for water and nutrients. It eventually dries and rots in the garden after the coffee seedlings are fully established. In addition, he waters the coffee seedlings in case of prolonged droughts.	This practice is not reflected in the coffee production manuals (Ministry of Agriculture Animal Industries and Fisheries, 1995b). It is practiced by over 50 farmers in the village. It is transferred from one farmer to another through existing extension system.
Soil fertility depletion results in reduced yield for both banana *(Musa species)* and coffee (*coffee cenephora)* crops. Climate change disasters e.g. prolonged droughts worsen the situation resulting in	Altered manure application method by applying manure in a pit established between 4 plants (banana/coffee). Francis Buzimba is the farmer innovator who is a member of Buzilango Farmer's Group.	Francis learnt this practice through trainings facilitated by extension officers and National Union of Coffee Agri-businesses and Farm Enterprises (NUCAFE). But they recommended application of manure in holes established between rows of the crops. Later on, he modified it by placing manure in holes between 4 plants because the earlier practice required a lot of manure which was not	Francis received initial technical advice from extension officers and NUCAFE. The banana production manual (NARO, 2001) does not emphasize this practice. The key challenges for the farmer innovator include: Lack of farm tools (wheel barrow, hoe, spade, gum boots)

household food insecurity and reduced incomes.	He practiced this for the over 5 years (see Figure 6).	available. One wheel barrow of composted manure (about 60-80 kg) is applied per hole per plant (coffee/banana) per year at planting. A year later, one wheel barrow of composted manure is added in holes established between 4 banana or coffee plants. The manure is covered with banana pseudo stems. And every month 15 litres of diluted pig urine per rectangular hip of manure are added. The rectangular holes are 2x1 m with a depth of 60 cm.	for preparation and application of manure; Farmer must have livestock as an immediate source of manure.
Insect pests especially banana weevil borers *(Cosmopolites sordidus)* destroys and weaken banana trees resulting in reduced yields and complete loss of banana plantations in the long term impacting on food security and income.	Control and management of banana weevils using hot pepper intercropped in the plantations. Francis Buzimba is the farmer innovator who is a member of Buzilango Farmer's Group. He has practiced this for the over 12 years (see Figure 7).	Planting hot pepper (*Capsicum sp.*) in the banana-coffee plantation and at maturity, hot pepper fruits are harvested and placed on the lower surface of the cut banana stems where they kill banana weevil borers after decomposition.	Francis learnt that hot pepper can be used in controlling crop pests during exposure visits during the time when he was a church leader. The banana production manual (National Agricultural Research Organization, 2001) does not emphasize this practice. Over ten farmers in the village are practicing this innovation. They learnt it from fellow farmers. However, the extension workers are not aware of this.

Table 9 Key informant's perceptions of major challenges limiting farmer innovations development process for climate change adaptation and mitigation in Uganda

Policy issue	Issue description	Strategies to address the issue
Limited support for farmer innovators in form of tools and financial resources to advance their innovations	Most of the time farmer innovators work with their own limited resources to develop the innovations. They are constrained by lack of tools, facilities and financial resources required to advance the innovations to the final stage. This limits most of them from turning their ideas into innovations.	Community development players such as Research Institutions, Agricultural Extension Workers and Non-Governmental Organisations (NGOs) should recognise farmer innovators so that they are motivated to further develop and promote their innovations. Such recognition could be in form of awarding certificates to outstanding farmer innovators. Furthermore, existing agricultural development programs should promote farmer innovations by providing support in form of tools and financial resources in form of small grants.
Weak linkages between famer innovators and Research and Development (R&D) Institutions	These weak linkages between the farmer innovators and research institutions mean that the innovators are working in isolation. Subsequently, the innovations are rarely validated and improved.	Research Institutions like National Agricultural Research Organisation and Universities should strengthen linkages and interactions with farmer innovators through creating and facilitating innovation platforms at local and national levels. In the process, the research institutions should support validation and value addition to the innovation. NGOs should support the identification and documentation of existing farmer innovations.
Many farmer innovations exist out there but are not known to R&D Institutions such as Research Institutions, Agricultural Extension Workers and NGOs.	Because many farmer innovations are not known to community development players, subsequently they are not documented. Consequently, they never inform agricultural policy and program implementation. Thus, they are rarely up and out scaled beyond their point of origin.	R&D Institutions such as Research Institutions, Agricultural Extension Workers and NGOs should identify, document and disseminate proven innovations so that they are up and out scaled to other areas.
Poor attitude of farmer innovators, researchers and development facilitators.	Often farmer innovators assume that the researchers and extension workers know it all and therefore should provide the solutions. On the other hand, the researchers and extension workers assume that the farmer innovators do not know anything. Hence, they have a mind-set of I know it all and are not very keen to observe what the farmers are doing.	Change the attitudes of farmer innovators, researchers and extension workers through continuous training and sensitisation workshops by existing initiatives, which are promoting innovations is agriculture and natural resources management (PROLINNOVA).

Table 10. Evaluation of climate change adaptation and mitigation innovations by smallholder farmers in Mpigi district, Central Uganda based on the TEES test.

Farmer innovation		
Creating shade for young planted coffee seedlings locally known as, 'okuwembela.'		
Evaluation using TEES test criteria	*Evaluation result*	*Comment*
Technically effective	√	The innovation effectively protects the young coffee seedlings from destruction by prolonged droughts.
Economically valid	√	The coffee (*coffee cenephora*) seedlings protected from prolonged drought survive to maturity and harvests made are translated into economic benefits for the farmer. Materials used are locally available.
Environmentally friendly	√	The innovation has no negative environmental effect. The plant used for shading can be planted on farm.
Socially acceptable	√	Innovation does not conflict with social and cultural norms of the farming community.
Farmer innovation		
Altered manure application method by applying manure in a pit established between 4 plants (banana (Musa spp.)/coffee)		
Evaluation using TEES test criteria	*Evaluation result*	*Comment*
Technically effective	√	The manure applied improves soil fertility and results in increased crop yields.
Economically valid	√	It increases crop yields which translate into economic benefits.
Environmentally friendly	√	It promotes soil carbon storage thereby contributing to climate change mitigation. It Improves soil organic matter, nutrient levels and associated biological, chemical and physical properties. Promotes judicious use of organic fertilizers and it is less labor intensive.
Socially acceptable	√	Innovation does not conflict with social and cultural norms of the farming community.
Farmer innovation		
Control and management of banana weevils using hot pepper (Capsicum sp.) intercropped in the plantations.		
Evaluation using TEES test criteria	*Evaluation result*	*Comment*
Technically effective	√	The innovation effectively controls banana weevils (*Cosmopolites sordidus*) in-situ inside the banana corms and other insects due to repellant effect of hot pepper.
Economically valid	√	The management of weevils results in increased banana yields, which translates into economic benefits to the farmer from the banana and additional income from hot pepper.
Environmentally friendly	√	It has no negative effects on the environment.
Socially acceptable	√	Innovation does not conflict with social and cultural norms of the farming community.

TEES refers to technically effective, economically valid, environmentally friendly and socially acceptable. It is used for evaluating the sustainability of the farmer innovations with consideration of the technical, economic, environmental and social parameters (Critchley et al., 2007). √ = yes, it meets the innovation criteria.

Paper III

Can Agroforestry Improve Soil Fertility and Carbon Storage in Smallholder Banana Farming Systems?

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Can agroforestry improve soil fertility and carbon storage in smallholder banana farming systems?

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Abstract

Soil fertility depletion is a major constraint to agricultural production for smallholder farming households in many sub-Saharan countries, and it is worsened by climate variability. In order to sustain food security for a growing population, measures have to be taken against C and nutrient losses from soils. This study examines whether banana–coffee agroforestry systems can improve soil fertility and C pools in smallholder farms in E Africa amidst observed climate variability. We selected 20 farms in Central Uganda, where soil samples were obtained from the top and subsoil layers. Samples were analyzed for several soil fertility parameters including soil organic matter (SOM), total soil organic C, pH, total N, plant-available P, exchangeable K, texture, and bulk density. Soil C stocks were calculated based on soil organic C concentrations and bulky density. We measured tree diameter and height and calculated aboveground plant biomass using allometric equations. Belowground biomass was estimated using equations based on the respective aboveground plant biomass. Our results show that banana–coffee agroforestry farming systems had significantly higher total SOM and total N compared to the banana monoculture. Similar trends were observed for soil C stocks and total C pools. The former contained 1.5 times higher soil C stocks than the latter. Likewise, the mean total C pools for the banana–coffee agroforestry farm plots were 26% larger than that under banana monoculture. However, exchangeable K was higher in the soil of banana monocultures. Plant-available P levels were limiting under both farming systems. The study demonstrates that beyond socio-economic benefits banana–coffee agroforestry farming systems have beneficial effects on soil fertility and C sequestration compared to banana monocultures in the study area. However, precautions to avoid P depletion have to be taken under current climate conditions.

Key words: biomass / banana–coffee agroforestry / climate change / soil organic matter / East Africa

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1 Introduction

Soil fertility depletion is a key development challenge in Uganda, as it is in many other sub-Saharan countries (*Stoorvogel* et al., 1993). It is a major constraint to agricultural production and food security for many smallholder farming households and is largely caused by poor soil management practices resulting in continuous nutrient removal (through crop harvest, uncontrolled soil erosion, and unregulated bush burning) without replacement (*NEMA*, 2001; *Olson* and *Berry*, 2003).

Future climate variability may exacerbate the reduction of soil fertility, thereby increasing food insecurity (*IPCC*, 2001; *Lal*, 2013; 2014). This will worsen the livelihoods of smallholder farmers who are already highly vulnerable and have limited adaptation capacities (*Morton*, 2007; *Harvey* et al., 2014). Climate variability, particularly prolonged droughts, strongly influences various processes such as mineralization of soil organic matter (SOM) and release of nutrients, which contribute to soil fertility depletion and degradation. Thus, higher temperatures and drier conditions in tropical regions have negative effects on SOM accumulation, resulting in poor soil structure and a reduction in rain water infiltration (*Rao* et al., 2007). In addition, an increase in the frequency of extreme rainfall events will cause greater soil erosion, resulting in further land degradation (*WMO*, 2005).

These trends all contribute to soil fertility depletion (*IPCC*, 2007; *Lal*, 2009), which can be described as negative nutrient balances for major plant nutrients (N, P, and K). This is already a significant challenge in tropical soils in sub-Saharan Africa (*FAO*, 1995; *Nkonya* et al., 2008). Over the past 30 years, soils in 37 African countries were estimated to have net nutrient balances of –22 kg N, –2.5 kg P and –15 kg K per hectare of cultivated land (*Sanchez*, 2002).

For Uganda in particular, earlier studies by *Stoorvogel* and *Smaling* (1990) already indicated that the national nutrient de-

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pletion was high for nutrient balances of major nutrients. They estimated it to range between 20–40 kg N ha^{-1} y^{-1}, 4–7 kg P ha^{-1} y^{-1}, and 17–33 kg K ha^{-1} y^{-1}. Furthermore, *Bazira* et al. (1997) reported net nutrient balances of –53 kg N ha^{-1} y^{-1}, –9 kg P ha^{-1} y^{-1}, and –58 kg K ha^{-1} y^{-1} in banana farming systems in the Lake Victoria crescent in Central Uganda. These figures depict that nutrient depletion of N and K at the national and farm scales for N and K in Uganda is much higher than that at the supra-national scale (sub-Saharan Africa). Thus, N and K are the most depleted nutrients at both national and farm scales. Despite this, the soil fertility status of smallholder banana farming systems in the context of climate variability has not been evaluated.

It is recommended that soil fertility depletion should be addressed through improvement of the soil physical, chemical and biological conditions (*Sanchez*, 1995; *Pinho* et al., 2012). *Rao* et al. (2007) argued that agroforestry systems can play an important role in addressing soil fertility depletion because of their comparative advantage to improving these conditions. They are also resilient (in terms of adaptation and mitigation) to climate variability impacts compared with agricultural monocultures (*Rao* et al., 2007; *Kerr*, 2012; *Charles* et al., 2013). Trees improve nutrient balances by reducing nutrient losses from erosion and leaching, and increasing nutrient inputs through N_2 fixation in the case of legumes. They also improve soil structure, water holding capacity, and crop rooting volume, and they increase biological activity in the soil by providing biomass and a suitable micro-climate (*Schroth* and *Sinclair*, 2003). However, trees in agroforestry systems have not been found to have any significant benefit to inorganic soil P so far (*Drechsel* et al., 1991; *Siaw* et al., 1991).

Pinho et al. (2012) noted that agroforestry trees contribute to the maintenance and improvement of SOM and N through increased inputs of litter and roots and a reduction in soil temperature through shading and soil protection from erosion. However, this depends on the type of agroforestry system and the soil and water management techniques being practiced (*Schroth* and *Sinclair*, 2003). In Uganda, smallholder farmers construct *fanya chini* and *fanya juu* for soil and water conservation within the agroforestry systems. *Fanya chini* are downhill ridges put on the lower side of contour trenches and established on gentle slopes, whereas *fanya juu* are uphill ridges established on steep slopes (*NARO*, 2001).

Organic matter, that comprises decomposed plant or animal material in the soil, provides nutrients and habitats to living soil organisms, and improves soil structure, cation exchange and water holding capacity (*Bot* and *Benites*, 2005). The addition of organic materials such as root biomass, livestock manure, and compost in farming systems has favorable effects on SOM, nutrients, pH, and other soil physical properties, such as water retention and temperature regulation (*de Ridder* and *Van Keulen*, 1990; *Bouajila* and *Sanaa*, 2011). Organic matter has a significant impact on soil fertility, considering its positive effects on soil chemical, biological and physical properties (*Craswell* and *Lefroy*, 2001). *Bot* and *Benites* (2005) reported that most soils contain 2–10% organic matter (OM). Organic C is a major component of SOM and an important global C storage pool. Thus, in most soils it is found in various forms, ranging from freshly deposited litter to highly decomposed stabile forms such as humus (*Schumacher*, 2002). In addition to their role in improving soil fertility, when designed and managed properly, agroforestry practices are also effective C sinks (*Montagnini* and *Nair*, 2004). Thus, studies by *Roshetko* et al. (2002), *Albrecht* and *Kandji* (2003), and *Oelbermann* et al. (2004) concluded that agroforestry systems make a significant contribution to C pools in the soil and aboveground biomass compared with agricultural monocultures.

Studies by *Albrecht* and *Kandji* (2003) and *Nair* et al. (2009) indicated that agroforestry systems have a C sequestration potential with a wide range of C stocks estimated between 12–228 t ha^{-1} and 1.3–173 t ha^{-1}, respectively. The amount of C stored largely depends on the agroforestry farming system in place, environmental and socio-economic factors at play, and tree species and management practices being used (*Albrecht* and *Kandji*, 2003).

Some studies on C pools under coffee agroforestry systems have also been conducted. For instance, *Dossa* et al. (2008) estimated aboveground plant biomass of 140 t ha^{-1} for *Coffea canephora–Albizia adianthifolia* (flat crown albizia) agroforestry systems in SW Togo. *Schmitt-Harsh* et al. (2012) reported aboveground C pools of 73 t ha^{-1} under coffee agro-forests in the Western highlands of Guatemala. Also, *Häger* (2012) estimated 25 and 63 t ha^{-1} of aboveground and soil C pools, respectively, in smallholder coffee agroforestry systems in Costa Rica. However, there is a dearth of information about C pools of smallholder banana (*Musa* sp.) monoculture (BM) and banana–coffee *robusta* (*Musa* sp.–*Coffea canephora*) (BCA) farming systems. In Uganda, 75% of smallholder farmers grow banana either as BM or BCA farming systems covering 1.5 million hectares of land, which constitutes 38% of arable land under use (*NARO*, 2001).

BCA is a traditional agroforestry system based on bananas as the main food crop and coffee as the main cash crop. Trees and shrubs are grown in the system for timber, fuel wood, fodder, medicinal, bark cloth, provision of shade for banana and coffee and other miscellaneous uses. Some of the tree species within this system include bark-cloth fig (*Ficus natalensis*), mango (*Mangifera indica*), umbrella tree (*Maesopsis eminii*), guava (*Psidium guajava*), flat crown albizia (*Albizia* spp.) and markhamia (*Markhamia* spp.). Conversely, the BM farming system is dominated by banana with no trees grown within the system (*Oduol* and *Aluma*, 1990). Smallholder farmers practice BCA farming systems because of its multiple benefits regarding food security and income generation (*Oduol* and *Aluma*, 1990).

In this study we evaluated the soil fertility status and C pools of smallholder BM and BCA farming systems in Central Uganda amidst climate variability impacts. Specifically, soil physical properties (*i.e.*, texture, bulk density, and depth), chemical properties (soil pH, total OM, organic C and N, exchangeable K, plant-available P, and soil C per hectare) under the two farming systems were determined. Furthermore, the stocks of aboveground and belowground C were estimated.

We hypothesized that given the prevailing climate variability in the study area, smallholder BCA farming systems improve soil fertility and C pools. Specifically, BCA should have higher levels of soil fertility parameters (total OM, organic C and N, exchangeable K, and plant-available P) and C pools (above-ground, belowground and in the soil). And hence, BCA should be more resilient to climate variability compared with BM.

2 Material and methods

2.1 Study site

The study was conducted in Uganda, the second largest producer of bananas in the world (*FAO*, 2010a). In Mpigi district Central Uganda there is evidence from smallholder banana farming communities that climate change is already negatively affecting livelihoods within the district. In Mpigi the study was conducted in two sub-counties: Nkozi and Kituntu. They were selected during an inception meeting with key stakeholders, including district and sub-county political officials from the production, environment and community development sectors. These two sub-counties were recognized as the most affected areas in the district by climate change disasters.

With an average population growth rate of 3.2% over the last decade, Mpigi district has a population density of 230 inhabitants per km^2, which is higher than the national average of 167 inhabitants per km^2 (*UBOS*, 2011). Soils are generally Ferralsols with combinations of clay and sandy loams, thus, classified as sandy clay loams. These soils are relatively fertile and favorable for crop production. However, poor farming practices have resulted in soil fertility depletion and low productivity in most parts of the district (*NEMA*, 2010).

The district has an altitude ranging between 1182 and 1341 m asl. and has a bimodal rainfall pattern with two rainy seasons occurring during March–May and September–November, respectively. The mean annual rainfall is 1320 mm with 10 average monthly days of rainfall (*NEMA*, 2010). Climate variability is a key challenge to agricultural activities, as prolonged droughts, heavy rains and hailstorms have already been reported causing destruction of plantations and increasing the risks of food shortages in many households (*NEMA*, 2010).

Subsistence agriculture is the major feature of the land-use system in Mpigi district with crop and livestock production as key enterprises. The district lies in the banana–coffee agroecological zone where the climate and soils have supported widespread production of banana and coffee (*MAAIF*, 1995a). The majority of farmers are smallholders with a land holding between 0.4 and 1.2 ha. Bananas, coffee, cassava (*Manihot esculenta*), sweet potatoes (*Ipomoea batatas*) and vegetables are the main crops being cultivated, of which bananas are a major food crop (*NEMA*, 2010).

2.2 Farms selection, sampling strategy, and soil collection

2.2.1 Farms selection

Simple stratified sampling was done to identify twenty smallholder farms (*i.e.*, BM and BCA) in Mpigi district. Thus, each

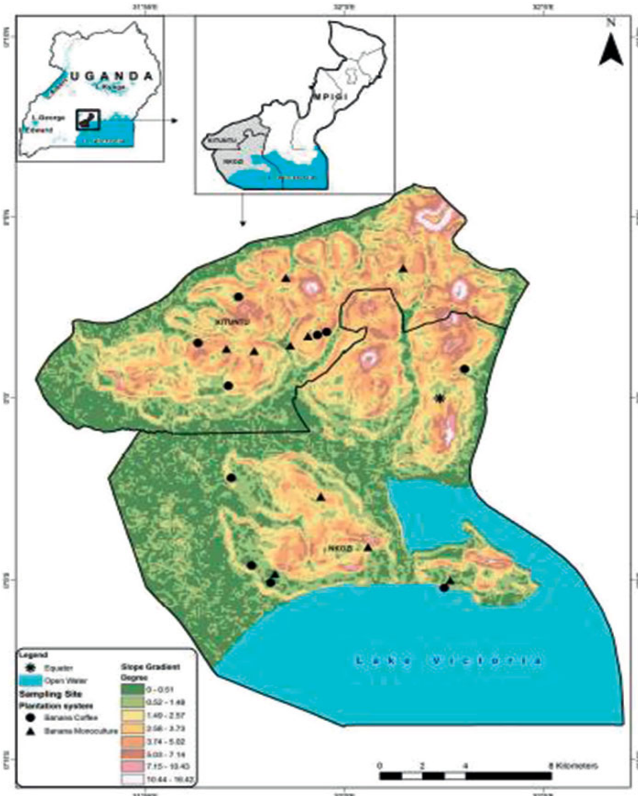

Figure 1: Location of selected farms in the Mpigi district, Central Uganda.

farming system constituted a stratum. The 20 farms were selected from existing official lists of registered farmers at community level. The key considerations were that these farmers were engaged in the production of banana and *robusta* coffee as major crops, either as banana monoculture or banana–coffee *robusta* agroforestry, and were located in the middle and middle lower slopes across the landscape. Ten farms were selected for each farming system and each farm was a replicate. The location of the selected farms in the study area was determined using global position satellite (GPS). Furthermore, digital elevation modeling was used to determine the slopes of the selected farms. Fig. 1 shows the location of the selected farms. Data forms were used to generate information about management practices on each of the selected farms through interviews with the farm owners. The plant density of major crops and trees on each of the selected farms was determined based on measurements of the spacing between the crops and trees, respectively using a measuring tape. See Table 1 for the description of the selected farms and Fig. 2 for photographs depicting BM and BCA farming systems on two of the selected farms.

2.2.2 Soil sampling

On each of the 20 selected farms, 12 soil samples were collected randomly from each 100 m x 100 m plot. These plots were located along flat plains within 20–40 m from the valleys, on areas with comparable soil types, rainfall amounts, and a variety of bananas and coffee, to minimize variations among plots. The samples were obtained from the top (A) and sub-

Figure 2: Left: Banana–coffee (*Musa* sp.—*Coffea canephora*) agroforestry farming system; Right: Banana (*Musa* sp.) monoculture.

Table 1: Description of selected farms in the study site in Mpigi district, Central Uganda[a].

Farm	Farm plant density			Manure applied	Manure input / t ha^{-1} y^{-1}	Mulching material used			SWC[d] practices	Farm age / y
	Banana	Coffee	Other trees			maize stovers	banana leaves and stems	nappier		
Banana–Coffee *robusta* (*Musa* sp. – *Coffea canephora*) agroforestry farming system										
1	771	771	20 J[b], 22 M[b]	Cattle	5.4	+[c]	+	–[c]	+	5
2	278	1111	35 BC[b]	Cattle	1.8	+	+	–	+	2.5
3	1111	625	10 M, 25 BC	Cattle	1.4	–	+	–	+	3
4	1111	772	50 BC and 6 J	Cattle	1.2	–	+	–	+	7
5	308	842	5 J, 25 BC, 5 U[b]	n/a[c]	0	+	+	–	+	4
6	1111	926	15 M and 5 A[b]	Cattle	4.2	+	+	–	+	7
7	1111	278	10 M and 12 A	Cattle	3.6	+	+	–	+	4
8	918	1111	15 BC and 5 J	Cattle	4.4	+	+	–	+	13
9	1111	1111	–	Cattle	3.6	+	+	–	+	7
10	1111	1111	82 M and 48 U	Cattle	2.7	+	+	–	+	4
Banana (*Musa* sp.) monoculture farming system										
11	1010	–	–	n/a	0	+	+	–	+	2
12	1111	–	–	Cattle	7	+	+	+	+	2
13	1111	–	–	Cattle	3.3	+	+	+	+	3
14	1111	–	–	Cattle	7	+	+	+	+	4
15	1736	–	–	Farmyard	1	–	+	–	–	16
16	1111	–	–	Cattle	8	+	+	+	+	20
17	1736	–	–	Cattle	2.8	+	+	+	+	8
18	1111			Cattle	3.6	+	+	–	+	4
19	1111	–	–	Cattle	5.3	+	+	–	+	3
20	1111	–	–	Cattle	3.6	+	+	–	+	5

[a]The average number of banana pseudo stems per hill was 3 under each farming system.
[b]M: mango (*Mangifera indica*); J: jackfruit (*Artocarpus heterophyllus*); BC: bark-cloth fig (*Ficus nantalensis*); U: umbrella tree (*Maesopsis eminii*); A: avocado (*Persea americana*).
[c]n/a= not applicable, + = yes, – = no.
[d]SWC = soil and water conservation practices such as f*anya chini* and *fanya juu*. *Fanya chini* refers to downhill ridges established on gentle slopes, whereas *fanya juu* refers to uphill ridges on steep slopes.

soil (B) layers using an auger. Thus, six soil sample replicates were collected from each soil layer. A total of 240 samples were analyzed for total SOM, total soil C, total N, plant-available P, exchangeable K, pH, and texture at the Soil and Plant Analytical Laboratories at the National Agricultural Research Laboratories (NARL), Kawanda.

Soil profiles were dug at each farm. For each profile, the depth of the top and subsoil layers was measured using a measuring tape. Furthermore, soil core samples were collected for each soil layer up to 20 cm in depth. The diameter of the soil core was measured, as well as the fresh weight of each core sample using a field scale. The oven dry weight at 105°C and bulk density of the soil core samples were determined at the Soil and Plant Analytical Laboratories at NARL using procedures described by *Blake* (1965).

2.2.3 Laboratory analyses

Soil samples were dried at 45°C in the oven for 2 d and later ground and passed through a 2 mm-sieve (*Gelderman* and *Mollarino*, 1998). Texture was determined using the buoycous hydrometer method (*Bouycous*, 1962). The total organic C was determined by the wet oxidation method using K-dichromate and sulfric acid (*Walkley* and *Black*, 1934). Total SOM was derived from total organic C using a conversion factor of 1.73 based on an assumption that OM contains 58% organic C (*Nelson* and *Sommers*, 1996).

Total N was determined using the Kjeldahl digestion based on procedures as stipulated by *Nelson* and *Sommers* (1972). A volumes of 2.5 mL of sulfuric/selenium digestion mixture were added to 0.3 g of dry soil sample in a digestion tube. The tube together with its contents was then digested at 330°C until the sample was burnt completely to ashes (white). The contents were left to cool and diluted with 50 mL of de-ionized water. An aliquot was picked and masked using N1 solution (Na-hypochlorite, Na-hydroxide) and later complexed using N2 solution (Na-nitro-pruside, Na-tartrate, Na-salicylate, Na-citrate). The color was left to develop for 30 min and absorbance read on UV-vis spectrophotometer at 655 nm.

The exchangeable K and plant-available P were extracted using the Mehlich III extraction method (*Mehlich*, 1984). In this process, 3 g of a well-ground soil (passing through a 2 mm sieve) was weighed and 30 mL of Mehlich III extracting solution was added. The solution was shaken at 200 rpm for 5 min. It was then left to settle for 10 min and later placed in a centrifuge at 2,000 rpm for another 5 min.

For the determination of exchangeable K, a precision pipette was used to measure 0.75 mL of the sample solution and standard. These were added to a 25 mL glass vial and rinsed with the same aliquot of 1,000 ppm La-chloride solution into the same glass vial. Another 13.5 mL of 1,000 ppm La-chloride (suppressant solution) was added to the glass vials. The exchangeable K^+ ions in the resultant solution were quantified on the atomic absorption spectrophotometer at 766.5 nm.

For measurement of plant-available P, a precision pipette was used to measure 1 mL of the sample and 1 mL of the standard. These were added into 25 mL glass vials and then rinsed with the same aliquot of distilled water into the same glass vial. A volume of 8 mL of Murphy–Riley working solution (sulfuric acid, NH_4-molybdate, K-antimony-tartarate, and ascorbic acid) was added. After 30 min the absorbance was read at 860 nm using UV-vis spectrophotometer.

Soil pH was measured based on the procedure described by (*Blakemore* et al., 1987). A 1:2.5 soil : water suspension was stirred and left to stand overnight. A portion of the suspension was extracted and measured using pH electrode to determine soil pH.

2.2.4 Calculation of soil C stock

The mean total organic C and bulk density were used to compute the soil C per plot up to 20 cm depth in the two soil layers for the respective banana farming systems. The results were extrapolated to generate soil organic C values on a ha-basis according to the following formulae by (*Murphy* et al., 2003):

$$\text{CD (Mg ha}^{-1}\text{) per soil layer} = \text{C (\%) x BD (Mg m}^{-3}\text{) x Layer depth (m) x 10000 (m}^2\text{ ha}^{-1}\text{)}, \quad (1)$$

where BD is the bulk density and CD is the soil C per hectare (SOC stocks).

2.2.5 Calculation of above- and belowground biomass

Aboveground plant biomass (AGB) of major trees (coffee, bananas, and key agroforestry tree species) was determined through random measurement of the diameter and height of at least three major tree species located within 100 m^2 of the selected smallholder farms. Tree height was also used to measure the coffee plants instead of girth, as the coffee plants had several stems standing from the base of the plant. The values obtained were used to estimate tree biomass using the allometric equations presented in Table 2. The results obtained were extrapolated to determine AGB on hectare basis (Mg ha^{-1}). The values of tree bulk density for each tree species were obtained from the global wood density database (*Zanne* et al., 2009).

Belowground biomass for each tree species was calculated according to *Cairns* et al. (1997; Table 2), as successfully applied to tropical regions in Africa (*Gautam* and *Pietsch*, 2012).

2.2.6 Calculation of above- and belowground plant C

The above- and belowground plant C for each tree species was computed as a fraction of the above- and belowground plant biomass, respectively. For bananas, coffee, and other tree species the biomass was multiplied by 37.9% (*Abdullah* et al., 2012), 45% (*Van Noordwijk* et al., 2002) and 50% (*Becker* et al., 2012), respectively. Total C pools under each were calculated by summation of aboveground, belowground and soil C in the soil layers (top and subsoil).

2.2.7 Statistical analyses

The results obtained for sand, silt, clay, soil layer depth, total SOM, total soil C, pH, total N, plant-available P, and ex-

Table 2: Equations used in the estimation of aboveground and belowground biomass for major biomass species in selected farms in Mpigi district, Central Uganda.

Major aboveground plant biomass species	Allometric equation used[a]	Authors
Musa sp. (bananas)	$AGB = 0.03(D)^{2.13}$	Arifin (2001; cited in *Hairiah* et al., 2001)
Coffea canephora	Log_{10} (AGB) = a+b x Log_{10} (h)	*Segura* et al. (2006)
Other tree species	$AGB = 0.112\ (rD^2h)^{0.916}$	*Chave* et al. (2005)
Major belowground plant biomass species	**Equation used**	**Authors**
Musa sp. (bananas), *Coffea canephora* and other tree species	$BGB = e^{(-1.0587 + 0.8836\ \ln AGB)}$	*Cairns* et al. (1997)

[a]AGB = aboveground plant biomass (Mg ha^{-1}); BGB = belowground plant biomass (Mg ha^{-1}); h (cm) = tree height; r (g cm^{-3}) = tree density; D (cm) = diameter of tree species; a = – 0.779; b = 2.338; Log = Logarithm.

changeable K were examined for normality and homogeneity using Microsoft Excel. Further analysis was done using a 2-factorial model to determine analysis of variance at 5% using GenStat 13. The sources of variation including farming system, soil level, and interactions between farming system and soil level for each of the soil chemical and physical parameters were separated. Sigma plot was used to generate graphs for aboveground plant biomass and mean C pools under BCA and BM farming systems.

3 Results

3.1 Farm age, manure input, and banana population

The mean farm age (6.7 ± 6.3 and 5.7 ± 3.1 years; $p = 0.64$) and annual organic manure input per hectare (4.2 ± 2.7 and 2.8 ± 1.7 t ha^{-1}; $p = 0.19$) under BM and BCA farming systems, respectively, were in a similar range ($p = 0.05$). However, the mean banana plant density per hectare under BM farming systems was higher than that under BCA farming systems by 27% (1226 ± 271 *vs*. 894 ± 337 t ha^{-1}, respectively; $p = 0.03$).

3.2 Soil fertility properties under banana farming systems in Central Uganda

3.2.1 Soil physical properties

Soil physical properties including texture, layer thickness, and bulk density are important for plant growth. They directly influence soil water holding capacity, storage, solute and water movement, and soil aeration. From Table 3 it is clear that soil physical properties (particularly texture and bulk density) for the selected farms in the study area are not significantly influenced by the farming system. However, the thickness of both the top and subsoil soil layers under the BM farming system was significantly higher than under the BCA farming system (9% and 20% higher, respectively; Table 3).

Table 3: Soil physical properties of smallholder banana farming systems in Mpigi district, Central Uganda[a].

Soil physical parameter	Top soil		Subsoil		P values of 2-way ANOVA		
					F[d]	S[d]	F*S
	BCA[b]	BM[b]	BCA	BM			
Sand / %	53.34 ± 6.9	52.35 ± 8.7	53.54 ± 9.6	52.59 ± 6.8	0.16	0.75	0.99
Clay / %	33.37 ± 6.7	34.08 ± 7.2	34.07 ± 6.2	36.27 ± 8.0	0.06	0.06	0.15
Silt / %	13.29 ± 4.6	13.73 ± 4.2	12.40 ± 3.5	11.14 ± 3.8	0.31	< 0.001*	0.04*
Textural class	sandy clay	sandy clay	sandy clay loam	sandy clay	n/a[c]	n/a	n/a
Bulk density	1.34 ± 0.3	1.40 ± 0.2	1.30 ± 0.28	1.39 ± 0.4	0.62	0.72	0.66
Depth of the soil layer / m	0.21 ± 0.04	0.23 ± 0.01	0.12 ± 0.03	0.15 ± 0.04	< 0.001*	< 0.001*	0.89

[a]All parameters are presented as mean values and their standard deviation.
[b]BCA = Banana–coffee *robusta* (*Musa* sp.–*Coffea canephora*) agroforestry system; BM = Banana (*Musa* sp.) monoculture system.
[c]n/a = not applicable; * = Significant difference between mean values at 5%;
[d]F = Farming system as a factor that influenced soil physical parameters; S = Soil layers as factor that influenced the soil physical parameters at 5%; F*S = Interaction between factors F and S and whether it influenced the soil physical parameters at 5%.

3.2.2 Soil chemical properties

3.2.2.1 Soil pH

In the study site, pH values in the top and subsoil layers under the BM and BCA were significantly influenced by the farming system. Thus, the pH of the top and subsoil layers under the BM system was 5% and 6% higher than that under the BCA system, respectively. Moreover, in both farming systems soil pH is favorably above the critical value (5.5) for crop production, except for the sub soil layer under BCA, which is slightly below the critical pH value (Table 4).

3.2.2.2 Total organic matter and C

Table 4 shows the total OM level of the top and subsoil layers under the BM and BCA farming systems. It was significantly influenced by the farming system as the total OM level in the top and subsoil layers under the BCA was 38% and 20% higher than under the BM farming system, respectively. However, the total OM levels under both systems were well above the critical total OM values.

It is not surprising that total organic C contents in the top and subsoil layers under BM and BCA followed a similar trend. Notably, the total organic C in the top and subsoil layers under the BCA farming system was 36% and 33% higher than under the BM system, respectively (Table 4).

3.2.2.3 Total N, exchangeable K and plant-available P

In the study sites, the levels of total N, exchangeable K in the top and subsoil layers were significantly influenced by the farming system (Table 4). The BCA exhibited higher total N levels in both soil layers compared to the BM farming system. It was 50% and 33% higher than under the BM system, respectively. The mean total N level in the top and sub soil layers of the BCA and BM farming systems was well above and equal to the critical values, respectively. Moreover, the BM farming system has a higher C/N ratio in both soil layers compared to the BCA farming system (Table 4).

On the contrary, the exchangeable K in the top and sub soil layers under the BM was 27% and 19% higher than that under the BCA farming system, respectively. The amount of exchangeable K quantity in the top and subsoil layers under both farming systems was well above the critical values (Table 4).

As for plant-available P, the farming system hardly influenced the respective levels in the top and sub soil layer under the BM and BCA farming systems. In addition, the level of plant-available P in the top soil layer for the BCA and BM farming system was far below the critical value, amounting to 33% and 39% of this value, respectively. On the other hand, it is 23% and 26% of the critical value in the subsoil layer for the BCA and BM farming systems, respectively (Table 4).

3.2.3 Aboveground biomass and C pools

3.2.3.1 Aboveground plant biomass

The major components of aboveground plant biomass on the selected farms are bananas, coffee, and other agroforestry tree species as illustrated in Fig. 3. The mean estimated aboveground biomass under BCA farming system was 16% higher compared to that under BM farming system. However, the mean values of estimated aboveground biomass under

Table 4: Selected soil chemical properties of banana farming systems in Mpigi district, Central Uganda[a].

Soil property	Topsoil		Subsoil		CV[d]	P values of 2-way ANOVA		
						F[f]	S[f]	F*S[f]
	BCA[b]	BM[b]	BCA	BM				
pH	5.6 ± 0.4	5.9 ± 0.7	5.4 ± 0.5	5.75 ± 0.8	5.5	< 0.01*	0.01*	0.81
SOM[c] / g kg^{-1}	82 ± 30	51 ± 15	55 ± 30	44 ± 16	30	< 0.01*	< 0.01*	< 0.01*
OC[c] / g kg^{-1}	47 ± 17	30 ± 9	37 ± 15	25 ± 8	n/a[e]	< 0.01*	< 0.01*	0.07
N[c] / g kg^{-1}	4 ± 1	2 ± 0.5	3 ± 1	2 ± 1	2	< 0.01*	< 0.01*	0.01*
K[c] / mg kg^{-1}	205 ± 92	279 ± 102	147 ± 65	181 ± 97	150	< 0.01*	< 0.01*	0.08
P[c] / mg kg^{-1}	30 ± 35	35 ± 35	21 ± 28	23.7 ± 28	90	0.33	0.01*	0.81
C:N ratio	11.75	15.00	12.33	12.45	n/a	n/a	n/a	n/a

[a]All parameters are presented as mean values and their standard deviation.
[b]BCA = Banana–coffee *robusta* (*Musa* sp.–*Coffea aenephora*) agroforestry system; BM = Banana (*Musa* sp.) monoculture system.
[c]SOM = Total soil organic matter; OC = Total soil organic C; N = Total N; K = Exchangeable K; P = Plant–available P; CV = Critical values of parameters for crop productivity. [d]CV source: *Okalebo* et al. (1993).
[e]n/a = not applicable; * = Significant difference between mean values at 5%;
[f]F = Farming system as a factor that influenced soil physical parameters; S = Soil layers as factor that influenced the soil physical parameters at 5%; F*S = Interaction between factors F and S and whether it influenced the soil physical parameters at 5%.

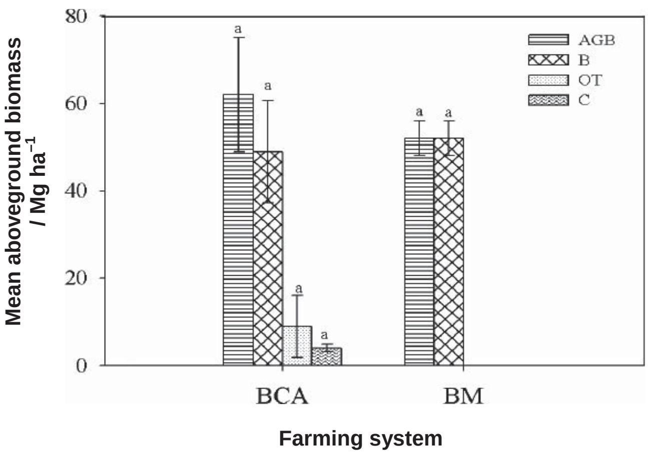

Figure 3: Components of mean aboveground biomass under selected smallholder banana farming systems in Mpigi district, Central Uganda. BCA = Banana–coffee *robusta* (*Musa* sp.—*Coffea canephora*) agroforestry farming system; BM = Banana (*Musa* sp.) monoculture farming system; AGB = aboveground biomass; B = banana (*musa* sp.); C = coffee *robusta* (*Coffea canephora*); OT = other agroforestry tree species such as mango (*Mangifela indica)*, umbrella tree *(Maesopsis eminii)*, bark-cloth fig (*Ficus Nantalensis)*, jackfruit (*Artocarpus heterophyllus)* and avocado (*Persea Americana).* Line error bars represent standard error of the mean. Two different letters above error bars for each variable between farming systems depict significant differences between the variables at 5%.

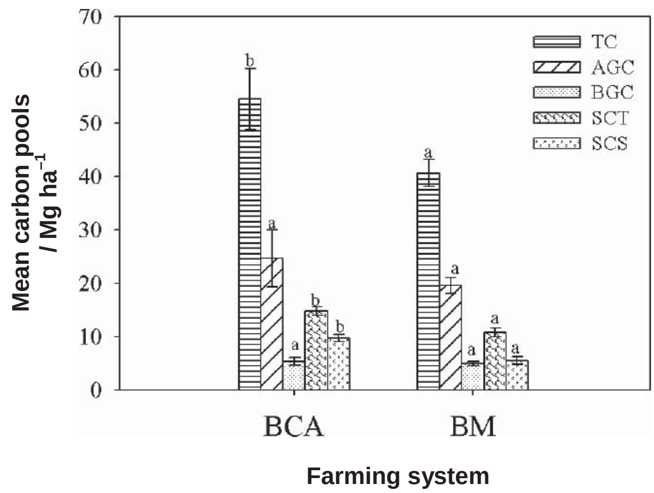

Figure 4: Mean C pools of smallholder banana farming systems in Mpigi district, Central Uganda. BCA = Banana–coffee *robusta* (*Musa* sp.—*Coffea canephora*) agroforestry farming system; BM = Banana (*Musa* sp.) monoculture farming system; TC = total carbon; AGC = aboveground plant carbon; BGC = belowground plant C; SC = soil organic C in the top soil layer; SCS = soil organic C in the subsoil layer; Line error bars represent standard error of the mean. Two different letters above error bars for each variable between farming systems depict significant differences between the variables at 5%.

both systems were similar at 5%. Banana contributed a large proportion of the aboveground biomass under both BM and BCA farming systems, 100% and 80% respectively (Fig. 3).

3.2.3.2 C pools

The total C pools under farming systems comprised of aboveground plant C, belowground plant C and SOC stock in 0 to 20 cm depth. The mean total C pool under the BCA was significantly higher (26%) than the BM farming system. The mean values of SOC stocks followed a similar trend displaying significantly higher in both layers (top and subsoil) under the BCA by 27% and 44%, respectively, compared to that under the BM farming system. Thus, the SOC stock under BCA was 1.5 times as much as that under the BM farming system. Conversely, the above- and belowground plant C pools under both systems were statistically similar at 5% (Fig. 4).

4 Discussion

Soil fertility and C pools depend on the farming system and the underlying soil management practices (*Schroth* and *Sinclair*, 2003). The results confirm the tested hypothesis, *i.e.*, BCA farming systems should have higher levels of soil fertility parameters (total OM, organic C and N, exchangeable K, and plant-available P) and C pools (in the aboveground plant biomass, belowground plant biomass and soil) compared to BM. This was true for soil fertility parameters (particularly for total OM, organic C, and N) and C pools (specifically total C and soil C pools). However, for exchangeable K and depth of layers (top and subsoil) the reverse was true. Thus, the BM had significantly higher levels of exchangeable K and depth of soil layers compared to the BCA farming system. Notably, both farming systems had comparable levels of plant-available P, aboveground plant biomass, and plant C pools in the above- and belowground.

The general characteristics of the selected farms, for instance the mean banana plant density per hectare, under the BM farming system was higher than the same banana plant density under the BCA. This is because in the latter farming system the plantation area was distributed among coffee and other agroforestry tree species in addition to bananas. On the contrary, the mean annual organic manure input on the selected smallholder farms under both farming systems were similar because the selected farms are located in the same area. Therefore, they had equal access to agricultural extension services (*Mpigi District Local Government*, 2009; *NEMA*, 2010).

The soil pH of the top and subsoil layers under both banana farming systems was favorably above the critical pH value of 5.5 preferred by most tropical crops (Table 3). It was within the required pH range (*i.e.*, 5.6–7.5 and 5.3–6.0) for banana and coffee production, respectively (*NARO*, 2001; *UCTF*, 2009).

The decomposition of organic materials such as manure, mulch, and tree litter fall contribute to the amount of OM, organic C, N, P, and K among other nutrients in the soil (*Bot* and *Benites*, 2005). Considering that the annual organic manure input per hectare under both farming systems was comparable, the significantly higher levels of total OM, organic C and N in the top and subsoil layers under the BCA compared to the BM is highly attributed to the additional amount and diversity in litterfall from coffee and other agroforestry tree species. Upon decomposition, these contributed to the total SOM, which directly influenced total organic C and N (*Celentano* et al., 2011).

The thicker top and subsoil layers under BM compared to BCA farming system (Table 3) was attributed to the accumulation of organic fragments in the soil (*Hillel*, 2008) as a result of mulching as a management practice (Table 1). Despite mulching being practiced under both farming systems in the BM, the composition of the mulching material used was different (Table 1). *Bekunda* (1999) and *Ollen* (2009) made similar reports that smallholder farmers use various materials such as dry grass and crop [maize (*Zea mays)*, beans (*Phaseola vulgaris*)] residues for mulching banana plantations in S Central Uganda and Central, E and W Uganda, respectively. Hence, some of the banana monoculture farmers from the study site reported the use of a combination of nappier grass (*Pennisetum purpureum*) in addition to maize stovers, banana leaves, and pseudo stems (Table 1). Nappier grass has a C/N ratio of 37 (*Flores* et al., 2012), which is higher compared to that for other mulching materials such as banana pseudo stems, banana leaves and maize stovers with a C/N ratio of 32 (*Salyeem* et al., 2014), 34 (*Salyeem* et al., 2014), and 23 (*Abdalla* et al., 2004), respectively. This translates into the higher C/N for the soil in the top layer under BM compared to BCA farming system (Table 4). Consequently this slows its decomposition (*Wortman* and *Shapiro*, 2012; *USDA*, 2011) resulting in the accumulation of organic fragments in the soil. In the BCA farming system, the majority of farmers used banana leaves, pseudo stems and maize stovers as mulching material.

The significantly higher level of exchangeable K in the soil layers (top and sub) under the BM (Table 4) is attributed to application of nappier grass (*Pennisetum purpureum*) in addition to maize stovers, banana leaves and pseudo stems (Table 1). The former has a high K content compared to maize stovers (*FAO*, 2012). It is assumed that the additional K in the soil was released through nappier grass decomposition.

It may seem surprising that aboveground and belowground plant C under both systems is comparable (Fig. 4). This can be explained by the fact that the coffee and other agroforestry trees species in BCA farming system contributed a smaller proportion of the total aboveground plant biomass (Fig. 3) and that bananas are the major contributors to the aboveground biomass plant under both farming systems (Table 4). Additionally, even when the bananas plant density under the BM was significantly higher compared to that under the BCA farming system, the C fraction for bananas is much lower compared to that of coffee and other agroforestry trees species at 37.9% (*Abdullah* et al., 2012), 45% (*Van Noordwijk* et al., 2002) and 50% (*Becker* et al., 2012), respectively.

Much of the mean total aboveground C and age of both farming systems were similar; under good management the mean total C pools under BCA farming system are likely to increase as a result of further growth of the coffee and other agroforestry tree species. This assumption is based on earlier reports by *Chauhan* et al. (2011) that C storage in poplar–wheat (*Populus* spp.*–Triticum* spp.) agroforestry systems in India increased with age.

However, the similarity of above- and belowground plant C under both systems raises a key question about the plant density under BCA regarding C storage. The recommended spacing for banana and coffee monocultures is 3 m x 3 m and 3 m x 3 m by *NARO* (2001) and *MAAIF* (1995b), respectively. Actually, no guidance is provided about spacing for inclusion of the other agroforestry trees. A banana : coffee ratio of 1:4 is recommended in the BCA farming system (*MAAIF*, 1995b). Notably, the existing recommendations for banana and coffee are aiming to maximize crop yield productivity, reduce the competition between both crops, and provide optimum shading to coffee by bananas. However, it is not necessarily promoting C storage or both attributes (*i.e.*, C storage and crop productivity) integrated. Therefore, optimum plant population targeting higher C storage and crop productivity as a win-win under BCA farming systems requires further investigation.

The C pools of the two banana farming systems studied is within the range of 12 to 228 t ha^{-1} for agroforestry systems as earlier estimated by *Albrecht* and *Kandji* (2003) and *Nair* et al. (2009). But it was higher than C pools for other agroforestry systems such as systems with diverse species including coconut palm (*Cocos* spp.), mangoes (*Mangifera* spp.), mexican lilac (*Gliricidia* spp.), coffee *robusta* (*Coffea canefora*) integrated with coral tree (*Erythrina poeppigiana)* alley cropping intercropped with crops, *i.e.*, maize (*Zea mays)*, beans (*Phaseolus* spp.), and cassava (*Manihotis esculenta*) estimated by *Roshetko* et al. (2002) and *Oelbermann* et al. (2004), respectively. The higher C pools of BCA and BM compared to other agroforestry farming systems can be explained by the management practices in the former, particularly the organic manure input and mulching materials application (Table 1). These contribute after decomposition to soil organic matter and C pools build up (*Schumacher*, 2002) in the farming systems, considering that C constitutes about 58% of the SOM (*USDA*, 2001).

The level of plant-available P in the soil layers (top and sub) under both BCA and BM farming systems were far below the critical value (Table 4), confirming that P is a key limiting nutrient for crop productivity—if not replenished, it reduces crop yields for both coffee and bananas. In the long term, it would cause food insecurity and reduced household incomes. Similar trends for P levels were earlier reported for 62 sites country-wide and in several areas for banana production in the Rwenzori region in Western Uganda by *Ssali* (2002) and *Rwenzori Regional Think Tank* (2011), respectively. The low levels of plant-available P could be attributed to the soil physical properties of the selected farms in the study area. These soils have a sandy texture (sandy clay and sandy clay loam), which are highly susceptible to nutrient loss through leaching including P (*Mylavarapu*, 2011), thereby resulting in reduced levels of plant-available P. Furthermore, there could be other factors (such as clay content) promoting P fixation by rendering it unavailable for plant uptake (*Batjes*, 2011). However, this requires further investigation. Additionally, site-specific management of P should be done to avoid blanket recommendations for P application.

In both farming systems, the main source of P is through application of organic manures. However, the mean annual application rates of 4.2 and 2.8 t ha^{-1} y^{-1} under BM and BCA, respectively, are far below the recommended rate of 20 t ha^{-1} y^{-1} of well composted organic manure (*NARO*, 1998). Ideally the P limitation would have been addressed through integration with inorganic P fertilizers but unfortunately only a few (1–5%) smallholder farmers use inorganic fertilizers (*Sseguya* et al., 1999) that are unaffordable to them (*Naakubuza* et al., 2005). Therefore, the appropriate alternative is the application of organic manure at the recommended rate considering that it is locally available.

In summary, this study has revealed that BCA farming systems improve soil fertility chemical parameters (particularly, total SOM and N). Earlier reports by *Neufeldt* et al. (2009) revealed that tree-based agricultural systems contribute to higher crop productivity, resulting in higher food security and increased incomes among the smallholder households. Furthermore, reports by *Van Asten* et al. (2011) indicated that intercropping of bananas and coffee is more economically beneficial compared to banana or coffee monocultures.

Up-scaling BCA from farm to regional and national scales would result in more C storage per hectare compared to the BM farming system. It requires adjustments in climate change, agricultural and environmental policies implementation to support this shift.

5 Conclusions

The current climate variability which has negative impacts on smallholder farmers' livelihoods calls for farming systems that are resilient in terms of adaptation to and mitigation of climate change. The study clearly demonstrated that BCA improves soil fertility and C sequestration compared to BM farming systems. Therefore, the BCA farming system would have a greater contribution to climate change adaptation (in terms of household food security and incomes) and mitigation through C storage in the soil, above- and belowground plant biomass. However, future research should focus on (1) the evaluation of C pools in deeper soil layers beyond the top and subsoil layers, (2) understanding the soil greenhouse gas emissions from BCA and BM farming systems, and (3) the establishment of optimal plant population for banana, coffee, and other tree species to achieve the desired triple win scenario of food security, climate change adaptation and mitigation under the climate-smart agriculture concept (*FAO*, 2010b; *World Bank*, 2013).

The following recommendations are suggested based on the study findings:

(1) More targeted awareness should be conducted among stakeholders at local (policy and decision makers) and community (smallholder farmers, farmers' associations, opinion leaders) level about the contribution of BCA farming systems to food security and climate change mitigation through C storage.

(2) Farmers adoption of BCA systems should be supported by providing incentives including recognition of outstanding BCA system farmers and access to credit and planting materials (*i.e.*, bananas, coffee and appropriate agroforestry tree species).

(3) Establishment of BCA farms at community level should be scaled up by increasing resources allocation for targeted awareness and training of stakeholders about establishment and management of BCA farming systems.

(4) Smallholder farmers should apply well-composted manure at the recommended rate of 20 t ha^{-1} y^{-1} to address soil P limitation. Initiatives that support them to access or produce their own manure, such as integrating livestock enterprises into their farming systems, should be equally supported.

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Part IV

4.0 General Discussion, Conclusion and Recommendations

4.1 Discussion

Climate change has significant implications on livelihood and economic development for all countries globally (Stern 2006). There is evidence for already existing climate change impacts (NAPA 2007; DSIP 2010; and NDP 2010) and according to Mendelsohn et al. (2000) these are projected to have major implications for agricultural development in Uganda like for many other sub-Saharan countries. The study in Mpigi district provides additional evidence in this respect, particularly on the following aspects: smallholder farmers' perceptions of the implementation of climate change disaster preparedness strategies (Zake and Hauser 2014a); smallholder banana farmers' innovations for climate change adaptation and mitigation (Zake 2014b); and resilience of smallholder banana farming systems under the prevailing climate variability (Zake et al. 2015).

The key results from the study are discussed as follows:

Farmers' perceptions of climate change disaster preparedness strategies implementation in Mpigi district

According to Zake and Hauser (2014a), the major climate change disasters due to climate change as perceived farmers were prolonged droughts, increased pests and diseases outbreaks in crops and livestock. This is in line with earlier reports on key disasters in Central Uganda and other parts of the country at large. Thus in this respect, NAPA (2007); National Disaster Preparedness and Management Policy (2010); NEMA (2010); and UNDAC (2008) reported prolonged droughts, heavy rains with hailstones and strong winds, increased incidence of pests and diseases as a consequence of climate change as the key disasters in Uganda. These climate change disasters indeed impact on community livelihoods and some of them include destruction of crops and death of livestock, leaving households without food. However, the reported impacts in Mpigi district have not reached extremes such as loss of property and lives (NAPA 2007; NEMA 2010). But considering the projected future climate variability, the associated impacts are likely to worsen (Wara et al. 2005).

Zake and Hauser (2014a) reported that farmers considered the implementation of climate change disaster preparedness at community and village level as inadequate. This triggered farmers' implementation of early actions as responses to climate change disasters. Hence, some of the early actions implemented against prolonged droughts included: planting drought-resistant crops, such as cassava; and indigenous crops such as arrow roots (*Maranta arundinaceae*) and upland yams (*Dioscorea* spp.). These actions constituted an informal disaster preparedness initiative at community level responding to climate change disasters in Mpigi district (Zake and Hauser 2014a). This is based on indigenous knowledge transferred to farmers through generations, earlier experience and knowledge with climate change disasters over the previous period among farmers. It is anchored by individual farmer's initiative with support from farmers' groups and non-government organisations operating at community level. Earlier studies by Anandaraja et al. (2008), Nguyen et al. (2009), Ogalleh et al. (2013), Roncoli et al. (2002) highlighted the importance of indigenous knowledge by communities to respond to natural disasters. It is important that this informal community-based disaster preparedness initiative is integrated with the formal initiatives to deliver more benefits through synergies (Makwara 2013).

Smallholder banana farmers' innovations for climate change adaptation and mitigation in Mpigi district

Climate change impacts triggered the development of innovations for adaptation and mitigation by smallholder banana farmers (Zake 2014b). Similar arguments were reported by LEISA (2000 and 2001) that traditional farmers have developed numerous indigenous farming systems adapted to several aspects of their environment (climate change inclusive) through innovation processes.

However, Zake (2014b) further observe that farmer innovators are faced with key challenges which must be addressed for promotion of their innovation development towards long term adaptation and mitigation of climate change impacts. Some of the major challenges as perceived by key informants in the study area include: Limited support for farmer innovators in form of tools and financial resources to advance their innovations; Weak linkages between famers' innovators and Research and Development (R&D) Institutions; Many farmer innovations exist out there but are not known to R&D Institutions such as Research Institutions, Agricultural Extension Workers and Non-Governmental Organisations; and Poor attitude of farmer innovators, researchers and development facilitators. These issues are similar to those reported by Sanginga et al. (2009), particularly the weak linkage between farmer innovators, public research, development organizations and private sector.

Resilience of banana farming systems under the prevailing climate variability conditions in Mpigi district

Zake et al. (2015) revealed that the BCA farming system had significantly higher total soil organic matter, and total N compared to the BM. Bot and Nenites (2005) observed that decomposition of organic materials such as manure, mulch and tree litter fall contribute to the amount of organic matter, organic C, N, P, and K among other nutrients in the soil. Therefore, considering that the annual organic manure input per hectare under both farming systems was comparable, the significantly higher levels of total organic matter, organic C and N in the top and sub layers under the BCA compared to the BM is highly attributed to the additional amount and diversity in litter fall from coffee and other agroforestry tree species. These upon decomposition contributed to the total soil organic matter which directly influenced total organic C and N (Celentano et al. 2011).

Likewise, the soil organic C and total C pools were significantly higher under the BCA farming system compared to BM. Thus, the former contained 1.5 times more soil organic C than the latter. The mean total C pools for the BCA farm plots were 26% higher than that under BM (Zake et al. 2015). The C pools of both banana farming systems is within the range of 12 to 228 t ha^{-1} for agroforestry systems as earlier estimated by Albrecht and Kandji (2003) and Nair et al. (2009). But it was higher than C pools for other agroforestry systems such as systems with diverse species including coconut palm (*Cocos*), Mangoes (*Mangifera*), Mexican lilac (*Gliricidia spp.*), Coffee robusta integrated with Coral tree (*Erythrina Poeppigiana)* alley cropping intercropped with crops i.e. Maize, Beans and Cassava estimated by Roshetko et al. (2002) and Oelbermann et al. (2004), respectively. The higher C pools of BCA and BM compared to other agroforestry farming systems can be explained by the management practices in the former, particularly the organic manure input and mulching materials application. These after decomposition contribute to soil organic matter and C pools build up (Schumacher 2002) in the farming systems, considering that C constitutes about 58% of the soil organic matter (USDA 2001).

Surprisingly, the exchangeable K in the top and sub soil layers under the BM was 27 and 19% higher than that under the BCA farming system, respectively. The amount of exchangeable K quantity in the top and sub soil layers under both farming systems was well above the critical values (Zake et al. 2015). The significantly higher level of exchangeable K in the soil layers (top and sub) under the BM is attributed to application of nappier grass (*Pennisetum purpureum*) in addition to maize stovers, banana leaves and pseudo stems. The former has high K content compared to maize stovers (Feedipedia 2012). It is assumed that the additional K in the soil was released through nappier grass decomposition.

The level of plant-available P in the top soil layer for the BCA and BM farming system was far below the critical value amounting to 33 and 39% of this value, respectively. On the other hand, it is 23 and 26% of the critical value in the sub soil layer for the BCA and BM farming systems, respectively (Zake et al. 2015). This confirms that P is a key limiting nutrient for crop productivity and if not replenished would result in reduction of crop productivity for both coffee and bananas. In the long term, this contributes to food insecurity and reduced incomes at household levels. Similar trends for P levels were earlier reported in 62 sites country-wide and in several areas for banana production in the Rwenzori region in Western Uganda by Ssali (2002) and Rwenzori Regional Think Tank (2011), respectively. The low levels of plant-available P could be attributed to the soil physical properties of the selected farms in the study area. They have sandy texture (sandy clay and sandy clay loam), which are highly susceptible to nutrient loss through leaching including P (Mylavarapu 2011) thereby resulting in reduced levels of plant-available P. Furthermore, there could be other factors (such as clay content) promoting P fixation there by rendering it unavailable for plant uptake (Batjes 2011). However, this requires further investigation. Additionally, site-specific management of phosphorus should be done to avoid blanket recommendations for phosphorus application.

Linkage between climate change disaster preparedness, adaptation and resilience of farming systems to climate change impacts

Reports by Klein et al. (2007) argue that climate change adaptation and mitigation actions are inter-linked at policy and practice levels. At the farm level, early actions against climate change disasters (Zake and Hauser 2014a) and the innovations for climate change adaptation and mitigation (Zake 2014b) by farmers in the study area are inter-linked and contribute to the resilience of the banana farming systems against climate change impacts (Zake et al. 2015). This is because some of early actions and or innovations by farmers contribute to various parameters which make the banana farming system more resilient. These parameters include: soil fertility improvement and maintenance; soil carbon storage; soil and water conservation; and crop pest and diseases management. For instance the construction of soil and water conservation trenches and the modification in manure application both contribute to soil fertility improvement and maintenance; soil carbon storage; and soil and water conservation. Similarly, the application of hot paper to control banana weevil borers support pests and diseases management in the banana farming systems.

Likewise, Dumanski (2004) and Savage (2011) observed that carbon storage in the soil present a commodity for farmers in the form of stored carbon. This makes their agricultural land more valuable through improving soil fertility, soil and water conservation thereby enhancing the farmer´s adaptive capacity (Butt and McCarl 2004). Opportunities for farmers to gain additional economic benefits from carbon credits through carbon offset initiatives like the Trees for Global Benefit Program by the Environmental Conservation Trust of Uganda (Masiga et al. 2012) should be explored.

4.2 Conclusions

The following conclusions are drawn in light of the study results:

a. Effective implementation of disaster preparedness strategies is required to avert the current negative climate change disasters impacts on community livelihood;
b. Recognition that farmer innovators are continuously working in the face of climate change disasters impacts to develop innovations for adaptation and mitigation;
c. Smallholder farmers' perceptions based on their knowledge and earlier experience about climate change should never be under estimated as a source of information for policy and program implementation. Thus, for cases where specific and localized metrological climate data is not available such information from farmers provides a key reference for early decision making during policy and program implementation;
d. Smallholder farmers are active victims of climate change. Besides the negative impacts associated with climate change, it also triggers farmers to develop beneficial practical solutions for adaptation and mitigation in form of farmer innovations;
e. The current climate variability in Mpigi district, which negatively impacts on smallholder farmers' livelihoods, requires farming systems that are resilient to climate change impacts. The study clearly demonstrated that banana-coffee agroforestry improves soil fertility and C storage compared to banana monoculture farming systems.

Future research
In light of the study results, further research studies should focus on the following:

a. Validation, documentation and dissemination of farmer innovations on climate change adaptation and mitigation through joint experimentation involving farmer innovators, researchers, extension workers, private sector and non-governmental organisations. Furthermore, the social-economic benefits of the farmer innovations regarding adaptation and mitigation to climate change impacts should be assessed;
b. Evaluation of C pools in deeper soil layers beyond the top and sub soil layers and understanding the soil greenhouse gas emissions from BCA and BM farming systems;
c. Establishment of optimal plant density for banana, coffee and other tree species to achieve the desired triple win scenario of food security, climate change adaptation and mitigation under the climate-smart agriculture concept (FAO 2010b and World Bank 2013).

4.3 Recommendations

The following key recommendations should be considered to advance climate change adaptation and mitigation in Mpigi district, Central Uganda:

a. The Department of Relief, Disaster Preparedness and Management under the Office of the Prime Minister should strengthen implementation of disaster management strategies at the local and village levels;
b. Research and Development Institutions and the Local Governments should support farmer innovators with inputs and financial resources to advance climate change adaptation and mitigation innovations development;
c. Up scaling BCA from farm to regional and national scales would result in more C storage per hectare compared to the BM farming system. It requires adjustments in climate change, agricultural and environmental policies implementation to support this shift. This should be spearheaded by the line ministries (i.e. Ministry of Agriculture, Animal Industry and Fisheries and the Ministry of Water and Environment) responsible for policy formulation;
d. The environment and agriculture based civil society organizations should create targeted awareness among stakeholders at local (policy and decision makers) and community (smallholder farmers, farmers' associations, opinion leaders) level about the contribution of BCA farming systems to food security and climate change mitigation through C storage;
e. The environment and agriculture based civil society organizations should strengthen their lobbying and advocacy engagement for increased resources allocation to support effective implementation of climate change adaptation and mitigation strategies at the national and local levels;
f. Smallholder farmers should be organised to access additional economic benefits from carbon credits through carbon offset initiatives. This could be arranged through collaboration between the civil society, private sector and government line ministries (i.e. Ministry of Agriculture, Animal Industry and Fisheries and the Ministry of Water and Environment).

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Appendix 1 - Study research phases

Research phases and key activities	**2011**		**2012**		**2012**		**2013**		**2013**		**2014**		**2014**		**2015**	
	Q 3	**Q 4**	**Q 1**	**Q 2**	**Q 3**	**Q 4**	**Q 1**	**Q 2**	**Q 3**	**Q 4**	**Q 1**	**Q 2**	**Q 3**	**Q 4**	**Q 1**	**Q 2**
Research Phase 1 - Coursework and PhD project proposal development at BOKU																
Key activities																
Administration and PhD project management																
Coursework																
Literature review and synthesis																
Development of research tools																
Research Phase 2 - Field studies in Mpigi district, Central Uganda (first trip)																
Key activities																
Conducting stakeholders inception workshops																
Pre-testing research tools																
Selection of respondents and farms																
Data collection																
Soil samples analyses																
Research Phase 3 - Data and knowledge management – at BOKU																
Key activities																
Data cleaning, coding and entry in Excel, SPSS and GenStat																
Data analyses and synthesis																
Development of manuscripts																
Research Phase 4 - Field studies in Mpigi, Central Uganda (second trip)																
Key activities																
Conducting dissemination and feedback workshops																
Collecting additional data about location of selected farms; aspects of farmer's innovations for climate change adaptation and mitigation.																
Key informant interviews on key climate change adaptation and mitigation policy issues in the agriculture sector in Uganda																
Research Phase 5 - Thesis writing and defense at BOKU																
Key activities																
Addressing reviewers comments on submitted manuscripts																
Writing PhD thesis and defense																

Shaded boxes indicate the period during the years (2011-2015) when the key activities were implemented. BOKU = University of Natural Resources and Life Sciences; Q = January, February, March; Q2 = April, May, June; Q3 = July, August, September; Q4 = October, November, December. Author´s table.

Appendix 2 – Soil analysis results for the samples collected in the top layer under banana farming systems in Mpigi district, Central Uganda

Farming systems	Replicate	Depth of top soil layer (m)	pH	SOM (%)	OC (%)	CD (Mg/Ha) per soil layer	N (ppm)	P (ppm)	K (ppm)	Sand (%)	Clay (%)	Silt (%)	BD (g/cc)
1	4	0.260	5.7	10.9	6.3	18.0	0.4	22.7	186.7	42.6	36.7	20.7	1.99
1	3	0.195	5.1	11.2	6.5	18.4	0.4	11.4	163.0	57.3	28.0	14.7	1.15
1	1	0.205	5.8	10.6	6.1	24.5	0.4	78.3	265.6	53.3	28.0	18.7	1.30
1	5	0.218	5.6	9.7	5.4	14.0	0.4	12.2	250.0	51.7	33.0	15.3	1.32
1	6	0.218	5.6	3.9	2.3	8.2	0.2	15.7	273.5	62.1	29.4	8.5	1.43
1	2	0.140	5.6	6.3	3.6	9.7	0.3	4.8	211.0	45.3	45.7	8.9	0.91
1	7	0.198	5.6	10.5	6.3	23.4	0.4	54.1	206.5	59.0	25.7	15.3	1.10
1	8	0.227	5.5	7.2	4.2	8.5	0.3	5.5	127.4	47.0	41.4	11.6	1.15
1	9	0.207	5.4	6.3	3.6	10.4	0.3	7.7	76.4	54.0	34.0	11.9	1.74
1	10	0.187	6.3	5.2	3.0	12.6	0.2	88.3	292.0	61.0	31.7	7.3	1.34
2	11	0.288	6.8	4.6	2.7	13.6	0.2	37.8	448.7	50.1	33.7	16.2	1.68
2	12	0.258	5.8	6.3	3.6	12.9	0.3	105.0	259.0	68.4	22.8	10.4	1.38
2	13	0.193	4.4	7.5	4.3	22.9	0.3	12.4	297.9	42.4	36.5	21.1	1.21
2	14	0.213	6.4	4.1	2.4	8.5	0.2	32.8	253.6	46.3	40.7	12.9	1.66
2	15	0.177	6.5	6.3	4.2	6.2	0.2	84.9	199.8	53.1	28.5	18.3	1.19
2	16	0.202	6.0	4.1	2.4	7.7	0.2	10.1	274.0	42.7	45.7	11.6	1.09
2	17	0.200	5.7	4.4	2.5	19.2	0.2	7.7	235.5	58.7	28.0	13.3	1.13
2	18	0.232	6,4	4.4	2.5	4.8	0.2	14.3	407.9	49.7	37.0	13.3	1.41
2	19	0.26	5.8	5.9	3.7	6.2	0.2	32.5	237.9	56.7	31.7	11.6	1.66
2	20	0.253	5.7	3.6	2.1	5.6	0.2	12.3	179.5	55.4	36.0	8.6	1.60

1 = Banana-coffee robusta (*Musa species-coffee cenephora*) agroforestry system; 2 = Banana (*Musa species*) monoculture system; OM = Total soil organic matter; OC = Total soil organic carbon; CD = soil carbon stocks; N = Total Nitrogen; K = Exchangeable Potassium; P = Plant-available Phosphorus, BD = Bulk density; m = meters; ppm = parts per million. Author´s table.

Appendix 3 – Soil analysis results for the samples collected from the sub layer under banana farming systems in Mpigi district, Central Uganda

Farming systems	Replicate	Depth of sub soil layer (m)	pH	OM (%)	OC (%)	CD (Mg/Ha) per soil layer	N (ppm)	P (ppm)	K (ppm)	Sand (%)	Clay (%)	Silt (%)	BD (g/cc)
1	4	0.113	5.5	9.8	5.9	18.0	0.4	7.5	133.1	41.8	37.9	20.3	1.62
1	3	0.09	4.8	8.5	4.9	18.4	0.4	4.2	130.2	58.5	28.2	13.3	1.3
1	1	0.127	5.5	8.5	4.9	24.5	0.3	82.7	190.9	58.7	28.7	12.6	1.2
1	5	0.135	5.2	5.3	3.2	14.0	0.2	5.2	145.1	51.0	35.8	13.2	1.4
1	6	0.135	5.0	3.8	1.7	8.2	0.2	7.7	206.9	61.6	29.4	9.0	1.1
1	2	0.100	5.6	5.4	3.1	9.7	0.3	3.9	115.9	45.4	44.4	10.2	1.2
1	7	0.153	5.3	0.5	4.9	23.4	0.4	36.7	163.5	60.3	26.2	13,5	13
1	8	0.118	5.5	4.7	2.7	8.5	0.2	3.4	87.3	48.9	41.5	9.6	0.9
1	9	0.108	5.4	4.9	2.7	10.4	0.2	4.7	71.1	53.2	35.0	11.8	1.4
1	10	0.117	6.8	4.0	2.3	12.6	0.2	50.9	221.2	55.8	33.7	10.5	1.8
2	11	0.130	6.7	3.8	2.2	4.6	0.2	53.2	408.5	48.7	38.4	12.9	1.9
2	12	0.098	5.7	4.6	2.6	8.9	0.2	42.3	164.8	71.3	22.7	6.0	1.0
2	13	0.148	4.0	5.8	3.5	7.6	0.3	4.2	121.4	42.7	39.0	18.3	1.3
2	14	0.160	6.2	3.1	1.8	4.5	0.2	11.5	128.5	46.7	43.0	10.3	1.2
2	15	0.152	6.4	6.8	3.8	12.3	0.3	83.9	158.9	55.0	34.4	10.6	1.2
2	16	0.138	5.7	3.6	2.1	5.3	0.2	3.1	158.9	42.3	47.8	9.9	1.7
2	17	0.152	5.5	3.3	1.9	3.9	0.2	4.1	90.3	60.0	27.7	12.3	1.9
2	18	0.165	6.3	3.7	2.1	8.2	0.2	8.6	291.5	49.0	39.0	11.9	1.6
2	19	0.145	5.4	6.6	3.2	11.9	0.3	18.8	180.5	52.4	35.7	11.9	1.2
2	20	0.140	5.6	2.8	1.6	3.1	0.2	7.4	109.8	57.7	35.0	7.2	0.9

1 = Banana-coffee robusta (*Musa species-coffee cenephora*) agroforestry system; 2 = Banana (*Musa species*) monoculture system; OM = Total soil organic matter; OC = Total soil organic carbon; CD = soil carbon stocks; N = Total Nitrogen; K = Exchangeable Potassium; P = Plant-available Phosphorus, BD = Bulk density; m = meters; ppm = parts per million. Author´s table.

Appendix 4 – Results for above-ground biomass under banana farming systems in Mpigi district, Central Uganda

Farming systems	**Replicate**	**Age (years)**	**Banana AGB (Mg/Ha)**	**Coffee AGB (Mg/Ha)**	**Other trees AGB (Mg/Ha)**	**Sum AGB (T/Ha)**
1	4	7	36.86	3.19	1.45	41.51
1	3	3	31.82	1.46	2.23	35.51
1	1	5	44.45	0.35	72.80	117.59
1	5	4	19.80	5.83	5.51	31.14
1	6	7	33.83	2.05	3.30	39.18
1	2	2.5	147.66	3.89	1.16	152.71
1	7	4	61.15	1.14	0.71	63.00
1	8	13	34.64	9.44	0.78	44.87
1	9	6	25.65	6.79	0	32.44
1	10	4	51.65	4.50	0.78	56.93
2	11	8	47.12	0	0	47.12
2	12	2	44.06	0	0	44.06
2	13	20	5.49	0	0	55.49
2	14	16	40.79	0	0	40.79
2	15	4	41.91	0	0	41.91
2	16	4	74.40	0	0	74.40
2	17	2	45.34	0	0	45.34
2	18	3	73.47	0	0	73.47
2	19	4,5	41.74	0	0	41.74
2	20	1,6	51.60	0	0	51.60

1 = Banana-coffee robusta (*Musa species-coffee cenephora*) agroforestry system; 2 = Banana (*Musa species*) monoculture system; AGB = aboveground plant biomass; Other agroforestry tree species such as Mango (*Mangifela indica)*, Umbrella tree *(Maesopsis eminii)*, Bark-cloth fig (*Ficus Nantalensis)*, Jackfruit (*Artocarpus heterophyllus)* and Avocado (*Persea Americana).* Author´s table.

Appendix 5 - Curriculum Vitae

Table 1. Personal information

Surname	Zake	
First name	Joshua	
Sex	Male	
Date of birth	16.07.1977	
Place of birth	Namirembe Hospital, Kampala District	
Marital status	Married	
Nationality	Ugandan	
Physical address	Nkokonjeru B LC1, Kyengera, Nsangi Sub County, Wakiso District	
Post Office box	P. O. Box 32066, Clock Tower, Kampala, Uganda	
Phone Number	+256712862050; +256773057488 and +256702160386	
Email address	joszake@gmail.com, jozake@hotmail.com or joszake@hotmail.com	
Personal website on Linked-in	http://ug.linkedin.com/pub/joshua-zake/23/45/181.	

Table 2. Education background

Year	Institution/School	Award
2011-2015	University of Natural Resources and Life Sciences (BOKU), Vienna Austria.	PhD in Natural Resources Management, specialization in Agricultural Sciences (expected).
2009	Wageningen University and Research Centre, Horn of Africa Environmental Centre, Association for Strengthening Agricultural Research in Eastern and Central Uganda RUFORUM and IUCN.	Certificate in Climate Change Adaptation in Agriculture and Natural Resources Management; Integrating Climate Change in Policy Making and Programming for Sustainable development.
2005-2008	Makerere University, http://caes.mak.ac.ug/.	Msc. Soil Science.
2004	Human Resource and Management Agency.	Certificate in Policy Analysis and Advocacy.
1998 – 2002	Makerere University, http://caes.mak.ac.ug/.	Bachelor of Science in Agriculture (Soil Science).
1996 – 1998	Makerere College School.	Uganda Advanced Certificate of Education.
1991 – 1995	Makerere College School.	Uganda Certificate of Education.
1983 – 1990	Nakasero Primary School.	Primary Leaving Examinations.

Research and scholarship awards received

Table 3. Key scholarship awards

Scholarship award	Purpose of scholarship/research award	Duration	Source of funding
Government of Uganda sponsorship for University Education	As facilitation to study a Bachelor of Science Degree in Agriculture at Makerere University	1998-2002	Government of Uganda
Scholarship for Higher Education and Research	As facilitation to study a Master of Science in Soil Science at Makerere University	2005-2008	European Union
International training course on climate change adaptation and mitigation in Agriculture, Environment and Natural Resources Management	To strengthen knowledge and skills on climate change adaptation and mitigation and integration in public policy implementation among key stakeholders in the Agriculture, Environment and Natural Resources Management sectors in the East African region	2009	Wageningen University and Research Centre
A scholarship by the Austrian Partnership for Higher Education and Research (APPEAR)	As facilitation for Doctoral studies in Environment and Natural Resources specializing in Agriculture at the University of Natural Resources and Life Sciences (BOKU), Vienna, Austria	2011-2015	The Austrian Development Cooperation
An award for graduate student research opportunity in climate risk management	As facilitation to strengthen knowledge and skills for climate threats and risks management	2012	The UK Department for International Development (DFID) and the Netherlands Directorate-General for International Cooperation (DGIS).

Other professional roles and responsibilities

a. Executive Board Member of Uganda Land Alliance Board (2006-2008);
b. Executive Board Member of the Non-Governmental Organization Network on Sustainable Land Management Committee (2006-2008);
c. Member of Committee for development of thematic paper for Environment and Natural resources to inform the development of the National Development Plan for Uganda (2007-2008);
d. Treasurer, Environmental Alert Staff Savings Scheme (2006-2008, 2009-2011);
e. Member of Makerere University Farmers Association (MUFA) (2000-2002);
f. Member of Makerere University Agricultural Students Association (MUASA) (1998-2002);
g. Member of the Soil Science Society of East Africa (SSSEA) (2002 to date);
h. Committee member to the SSSEA Executive-Uganda Chapter 2004-2007;
i. Member of Environmental Alert Management Team, 2008-2010.

List of selected publications:

Scientific articles

Zake, J., Pietsch, S. A., Friedel J. K., Zechmeister-Boltenstern, S. (2015). Can Agroforestry Improve Soil Fertility and Carbon Storage in Smallholder Banana Farming Systems? *J. Plant Nutr. Soil Sci.* 2015, 000, 1–13. doi: 10.1002/jpln.201400281

Zake, J. and Hauser, M. (2014a). Farmers' perceptions of implementation of climate variability disaster preparedness strategies in Central Uganda. *Journal of Environmental Hazards*. doi:10.1080/17477891.2014.910491.

Snijders, P., van der Meer, H., Onduru, D., Ebanyat, P., Kabebe, E., Zake, J., Wouters, B., Gachimbi, L., van Keulen, H. (2013). Effects of cattle and manure management on the nutrient economy of mixed farms in East Africa: A scenario study. *African Journal of Agricultural Research 8(41):5129-5148.* doi: 10.5897/AJAR10.009.

Zake, J., Kitungulu, J.Y.Z., Busurwa, H., Kyewaze, F. (2011). Sustainable use of wetland soils in the Eastern region of Uganda around the Lake Victoria Basin, 2011. *Water and Practice Technology Journal Vol 6 No. 3*. doi:10.2166/wpt.2011.05.

Zake, J. Tenywa, J. S., Kabi, F. (2010). Improvement of Manure Management for Crop Production in Central Uganda. *Journal of Sustainable Agriculture, 34: 6, 595-617.* doi:10.1080/10440046.2010.493368.

Snijders, P., Onduru, D., Wouters, B., Gachimbi, L., Zake, J., Ebanyat, P., Ergano, K., Abduke, M., van Hernan, K. (2009). Cattle manure management in East Africa: Review of manure quality and nutrient losses and scenarios for cattle and manure management. Report 258. Wageningen UR Livestock Research, Wageningen.

Zake J., Tenywa J., S. and Kabi F. (2005). Enhancement of manure utilization in smallholder cattle management systems for crop production in Central Uganda. *ACSJ, (7), 1067-1071.*

Monograph

Zake, J. (2008). Enhancement of cattle manure quality and utilization for crop production on smallholder farming systems in central Uganda. Master’s thesis, Makerere University, Kampala.

Conference and workshop contributions

Zake, J. (2009). Agroforestry practices and application on smallholder organic farms. Training notes prepared and facilitated during a training workshop for smallholder farmers in Mitiyana to enhance their skills in the application of agroforestry practices and principles in organic agriculture farming systems. African Institute for Capacity Development, Kampala.

Nyende, P., Zake, J., Rusoke, C. (2006). Land and water management farmer field schools: A review of the process in Uganda. A paper presented in a workshop on Farmer Field Schools Experiences on Land and Water Management in Africa, 24– 29th April 2006, Nile Resort Hotel, Jinja.

Opondo, C., Zake, J., Stroud, A., Tanui, J., Lutalo, R., Kanzikwera, R. (2005). From Reductionism to Local Innovation systems: Implications for Multi-stakeholder collaborative Learning and Client–orientation in Uganda. A paper presented in a Global Learning event – Conference in September 2005. International Farming Systems Association (IFSA), Rome.

Case studies

Zake, J. (2012). Adaptation, early action and mitigation for climate variability impacts; A case of Francis Buzimba Mugerwa - a smallholder farmer in Mpigi district, Central Uganda. http://start.org/download/2012/drr/zake-case-study1.pdf.

Zake, J. (2012). Adaptation to prolonged droughts in Central Uganda; appropriate irrigation technology as a practical option for smallholder farmers. http://start.org/download/2012/drr/zake-case-study2.pdf.