TECHNISCHE UNIVERSITÄT DRESDEN
FACULTY OF ENVIRONMENTAL SCIENCES
&
UNITED NATIONS UNIVERSITY
INSTITUTE FOR INTEGRATED MANAGEMENT OF MATERIAL FLUXES AND OF RESOURES

Integration of Organic Farm Waste into Smallholder Banana-Coffee-Based Farming Systems in the Kagera Region, NW Tanzania

DISSERTATION

Submitted for the award of the degree
Doctor of Philosophy (Ph.D.)

by

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Diploma in Geoecology
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Date of Defence:	14th January 2022

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Acknowledgements

It was an honour to be part of the *Joint PhD Programme in Integrated Management of Water, Soil, and Waste*, run by the United Nations University Institute for Integrated Management of Material Fluxes and of Resources and by the Faculty of Environmental Sciences at the Technische Universität Dresden. I gratefully acknowledge the United Nations University, the Heinrich Böll Foundation, and the Deutsche Gesellschaft für Abfallwirtschfaft e. V. for funding. I sincerely thank my supervisors Prof. Dr. Karl-Heinz Feger, Dr. habil. Kai Schwärzel, Prof. Dr. Gerald Kapp, and Prof. Dr. Christina Dornack for their tireless support and their professional and critical feedback, and to Prof. Dr. Maria Blanco and Dr. Lulu Zhang who served as reviewers, and to Prof. Dr. Edeltraud Günther for inspiring me to use 'mixed methods'. My sincerest thanks also go two Tanzanian non-profit organisations: the MAVUNO Project and 'Women and Men for Destined Achievements' (WOMEDA) in particular Charles Bahati, Juma Masisi, Adam Bitakwate, Ibrahim Bamuhiga, Leinalida Alichard, Harriet Robert and Godson Byamungu, for their close and sincere cooperation, and without whom the data collection would not have been possible; and Abel Leonard Mtembejji and Joana Lapao Rocha for their incredible commitment during the fieldwork – I appreciate their constant support and honest communication and look back fondly on the fun we had. I hope that this research will help support both organisations to further develop their outstanding work on sustainable food systems and to serve as best-practice examples for other farmer field schools, non-profit organisations, and governmental initiatives. Special thanks are also due to Dr. Ariane Krause (Technische Universität Berlin) for putting me in touch with the MAVUNO Project and for inspiring my research, Shadrack Stephene (National Land Use Planning Commission, Tanzania) for explaining Tanzanian land-use policies to me and connecting me with WOMEDA, to Prof. Dr. Frederik Baijukya (International Institute of Tropical Agriculture) for teaching me how farming systems developed in Karagwe, and to Dr. Sekela Twisa and Dr. Mohamed Mwabumba (Meteorological Agency, Tanzania) for hosting me in Dar es Salaam and accompanying me when meeting officials. I also gratefully thank Atiqah Fairuz Salleh, Claudia Matthias, Helen Grützner, and Andreas Schulze for the graphical realisation and for editorial advice during publication of the research findings. My warmest thanks go to all the PhD students on our Joint PhD Programme – in particular to Dr. Agossou Gadedjisso-Tossou, Dr. Thuy Hoang Nguyen, Dr. Solomon Hailu Gebrechorkos, Dr. Sekela Twisa, Dr. Mahesh Jampani, Dr. Janis Kreiselmeier, Dr. Parvathy Chandrasekhar, , Dr. Sridhar Patra, Andrea Müller, Isabella Georgiou, and Shadrack Stephene – with whom it has always been a pleasure to work, and to our great community that has grown together in difficult and joyful moments alike . My heartfelt thanks go to my wonderful family: Marisa, Astrid, Christian and Thomas Reetsch and Alexander Schrode, and my lovely friends. --- *Thanks to all of you, Anika*

Note by the author:

The cumulative dissertation is written in British English. Please note that grammar and spelling within this thesis may vary between British and American English between chapters due to the individual publishing requirements of different publications.

Integration of Organic Farm Waste into Smallholder Banana-Coffee-Based Farming Systems in the Kagera Region, NW Tanzania

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Abbreviations and acronyms

AIDS	Acquired immunodeficiency syndrome
Al	Aluminium
asl	Above sea level
av.	Average (mean value)
Ca	Calcium
CaSa	Carbonisation and sanitation
CE	Circular economy
Cont.	Continuing
Crantz	Heinrich Johann Nepomuk von Crantz (1722 – 1799), Austrian physician and botanist
DIN	Dissolved inorganic nitrogen
DM	Dry matter
DON	Dissolved organic nitrogen
DGAW	Deutsche Gesellschaft für Abfallwirtschaft e. V.
E	East
EAHB-AAA	East African Highland Banana, subgroup of triploid (AAA genome) bananas
et al.	*Et alia / alii* (meaning 'and others' in Latin)
FAO	The Food and Agriculture Organization of the United Nations
Fe	Iron
FFS	Farmer field school
FGD	Focus group discussion
HCA	Hierarchical cluster analysis
HIV	Human immunodeficiency virus
ibid.	*Ibidem* (meaning 'in the same place' in Latin)
IITA	The International Institute of Tropical Agriculture
IN	Inflow
K	Potassium
L.	Carl von Linné (1707 – 1778), Swedish natural scientist
MAVUNO	MAVUNO Project is a non-profit organisation in Karagwe, NW Tanzania. (*Mavuno* means harvest in Kiswahili).

max.	Maximum value
MFA	Material flow analysis
Mg	Magnesium
min.	Minimum value
N	Nitrogen
n.a.	Not analysed
NB	Nutrient balance
n. d.	No data
n. r.	Not relevant
NLUPC	The National Land Use Planning Commission of Tanzania
NPK	Nitrogen, phosphorus, and potassium
Nutr.	Nutrients
NW	Northwest
OM	Organic matter
OUT	Outflow
p.	Page
p.p./pp.	Pages
P	Phosphorus
PCA	Principal component analysis
P_{cal}	Phosphorus extracted in a calcium-acetate-lactate solution
pH_{KCl}	pH-value in potassium chloride
PN	Particulate nitrogen
PP	Particulate phosphorus
pst.	Pseudostem
Rob.	Robusta
S	South or sulphur
s. d.	Standard deviation
SDG	Sustainable Development Goal
Si	Silicon
Sims	John Sims (1749 – 1831), English physician and botanist
SLM	Sustainable land management
SNB	Soil nutrient balances
SOM	Soil organic matter

spp.	Species
SSA	Sub-Saharan Africa
SUA	Sokoine University of Agriculture in Tanzania
T	Trained
TDN	Total dissolved nitrogen
TDP	Total dissolved phosphorus
TMA	The Tanzania Meteorological Agency
TN	Total nitrogen
TP	Total phosphorus
TV	Television
U	Untrained
UDDT	Urine-diverting dry toilet
UN	United Nations
UNU	The United Nations University
URT	The United Republic of Tanzania
vs	Versus
W	West
WEF	Water-Energy-Food Nexus
WHO	The World Health Organization
WOMEDA	'Women and Men for Destined Achievements' is a non-profit organisation in Karagwe, NW Tanzania
WEF	Water-Energy-Food Nexus
WSW	Water-Soil-Waste Nexus

Units

°C	Degree Celsius
cm	Centimetre
cmol	Centimole
cg	Centigram
d	Day
dm^3	Cubic metre
g	Gram
ha	Hectare
hh	Household
kg	Kilogram
km	Kilometre
km^2	Square kilometre
kW	Kilowatt
L	Litre
m	Metre
m^2	Square metre
mg	Milligram
mm	Millimetre
%	Percent
pers.	Person
t	Ton
TLU	Tropical Livestock Unit, 1 TLU = 150 kg of livestock
USD	US Dollar
vol%	Volume percent
yr	Year

Abstract

In the studied Kagera region (NW Tanzania), smallholder banana-coffee-based farming systems developed over hundreds of years. To this day, they traditionally consist of four components: the older and younger homegardens (*kibanja* and *kikamba* in the local Bantu language), woodland (*kabira*), and grassland (*rweya*). The management of organic farm waste has played an essential role in maintaining soil fertility, diversity, and agricultural productivity in these agroforestry systems. However, rapid population growth since Tanzania's independence in the 1960s, an influx of refugees in the 1990s, and accompanying environmental degradation have shaped large parts of the study region. As a result, farm sizes, crop yields, and food security have declined, soils and farming systems have degraded, and impoverishment has increased. The overall objective of this study was to investigate whether degraded homegardens can be transformed back into multifunctional, sustainable, and fertile agroforestry systems through sustainable organic farm waste management. Organic farm waste embraced crop and tree residues, kitchen and food waste including cooking ash (as inorganic residue), livestock manure and urine, animal bones, as well as human faeces and urine. The objective was subdivided into three targets and related research foci: (1) to understand the *status quo* of organic farm waste management in the research area, (2) to evaluate modification options for sustainable banana-coffee-based systems, and (3) to evaluate an optimisation of organic farm waste management to increase agricultural production. An interview of 150 smallholder households on the current availability and uses of organic farm waste was conducted (1). The survey encompassed geographical variables, economic data, and household and agricultural information relating to the Water-Soil-Waste Nexus and the Water-Energy-Food Nexus. A farm household typology was constructed to categorise the farm households according to their biomass production and use of organic farm waste. Five focus group discussions were held in a local farmer field school to evaluate a training on sustainable land use management (2). The farmer field school had trained about 750 farm households in degraded banana-coffee-based farming systems in the last two decades. Also here, a typology construction of trained farm households was created. Both typologies were compared to each other. Nutrient cycles of the homegardens of trained and untrained farm households were calculated (3) using the following scenarios: S0: business as usual; S1: the use of 80% of the available human urine; S2: the incorporation of 0.5 t yr^{-1} of the herbaceous legume species *Crotalaria grahamiana* into the soil; S3: the production of 5 m^3 yr^{-1} of CaSa-compost (human excreta and biochar) and its application on 600 m^2 of land; and S4: a combination of S1, S2, and S3.

Results revealed that integrated organic farm waste management still plays a key role in farm nutrient and soil fertility management in these farming systems, but to a lower extent

than in the past (*status quo*). Smallholder farmers that apply organic farm waste to their fields – using *in situ*, pit, ring-hole, and mixed composting techniques – have higher yields. However, the knowledge on waste management – traditionally passed on from generation to generation – has declined. Today, only one third of these households earn a reasonable living from their agricultural products. Female-led households with a high age-dependency ratio and farmers with problematic socio-economic backgrounds continue to be the most vulnerable to food insecurity. In comparison, the implementation of training on sustainable land-use management has considerably improved farmers' livelihoods. Successfully implemented knowledge on sustainable soil and farm nutrient management, including the modification of composting techniques, afforestation, selection of appropriate crop and tree species, improved labour allocation and time management, agricultural record-keeping, as well as gender-responsive communication and decision-making, has led to a transition: from degraded agricultural to multifunctional agroforestry systems. However, also here, one third of the trained farmers has hardly transformed at all and has remained vulnerable to difficulties with food security, income diversification, and access to education. Comparing the nutrient balance between the homegardens of untrained and trained households, the homegardens of trained households are more likely to have a positive nutrient balance than those of untrained ones. Although untrained households would improve the nutrient balance under all management scenarios, their nutrient balances do not actually turn positive, especially not for nitrogen. Besides, nutrient cycles in the homegardens of all households remain 'open' because farmers currently import nutrients from the surrounding area, e.g., through fodder from the grassland. To overcome this dependency, short-term nutrient deficiencies might be alleviated with a precise application of mineral fertiliser and by fostering zero grazing. However, limited access to mineral fertiliser, labour-intensive manure collection and compost production against a background of land scarcity, labour shortage, prolonged dry seasons, and socio-economic imbalances, remain major challenges. To conclude, action needs to be taken and supporting policies and regulations need to be developed, e.g., on the safe use of organic farm waste and wastewater in smallholder agriculture to contribute towards achieving key Sustainable Development Goals of the United Nations. The relevant goals are Goal 2 (Zero hunger), Goal 7 (Affordable and clean energy), and Goal 15 (Life on land). None of the untrained smallholder households lives under the conditions that these goals intend to prescribe. Only one-third of the trained farming households is one step closer to achieving these targets. To counteract this, a roadmap may serve as a starting point for future initiatives to develop coherent policies and science-based guidelines.

Zusammenfassung

Bananen-Kaffee-basierte Anbausysteme haben eine lange Tradition in Ostafrika. In der Kagera-Region im Nordwesten Tansanias entwickelten sich über Jahrhunderte hinweg ertragreiche Bananen-Kaffee-basierte Anbausysteme in kleinbäuerlicher Landwirtschaft. Diese bestehen bis heute aus vier Landnutzungsarten: den Hausgärten, die sich aus älteren und jüngeren Feldern (*kibanja* und *kikamba* in der lokalen Bantu-Sprache) in unmittelbarer Nähe der Bauernhäuser zusammensetzen sowie dem daran anschließenden Wald- (*kabira*) und Grasland (*rweya*). In den Hausgärten wuchsen ursprünglich eine Vielzahl von ein- und mehrjährigen Kulturpflanzen dicht neben einander in unterschiedlicher Höhe. Die Böden der Hausgärten waren durch die kontinuierliche Zugabe von kompostierten organischen Abfällen dunkel, humusreich und fruchtbar. Langfristig trug die traditionelle Düngung mit allen zur Verfügung stehenden organischen Abfällen nachhaltig zur Humusanreicherung sowie zur Erhaltung der Bodenfruchtbarkeit und damit zur Sicherung der landwirtschaftlichen Produktion bei. Jedoch verlor dieses nachhaltige Agroforstsystem in der Kagera-Region in den letzten 50 Jahren zunehmend an Bedeutung. Die Gründe dafür waren in erster Linie der rasche Anstieg der Bevölkerung seit der Unabhängigkeit Tansanias in den 1960er-Jahren sowie der Zustrom von Flüchtlingen in den 1990er-Jahren. Beides führte zu einer Erhöhung der Nachfrage nach Nahrungsmitteln, Baumaterial und Brennholz, die noch immer wichtigste Energiequelle zum Kochen. Anfänglich konnte der erhöhte Bedarf durch einen Anstieg der landwirtschaftlichen Produktion gedeckt werden, doch nur mit einhergehender Degradierung, massiver Entwaldung sowie nachlassender Erhaltung der Bodenfruchtbarkeit und das Auslassen notwendiger Brachzeiten und Gründungen. Infolgedessen wurden den Böden über fünf Jahrzehnte mehr Nährstoffe entzogen als zugefügt, was zu einer Abnahme der Bodenfruchtbarkeit führte. Erschwert wurde die Lage kulturell und sozio-ökonomisch durch den Ausbruch von HIV und Aids in den 1980er-Jahren. Die Weitergabe von traditionellem landwirtschaftlichem Wissen wurde oftmals durch den Tod eines oder mehrerer Familienmitglieder an die nachfolgende Generation unterbrochen. Die Folgen waren gravierend: Die Ernteerträge aller ein- und mehrjährigen Kulturpflanzen sind zurückgegangen und die Böden sowie die Vegetation der Hausgärten sind teilweise stark degradiert. Seitdem sind die Ernährungssicherheit und der Wohlstand der lokalen Bevölkerung sowie die für Tansanias Wirtschaft wichtigen Exporte von Bananen (*Musa* L.) und Kaffee (*Coffea canephora* L. var. *robusta*) aus der Kagera-Region gefährdet.

Ziel dieser Dissertation war es, zu untersuchen, ob der jetzigen Degradierung der Hausgärten, die für die Ernährungssicherung der Bevölkerung entscheidend sind, durch eine erneute, stärkere und nachhaltige Einbindung organischer Abfälle entgegengewirkt werden

kann und so wie einst multifunktionale, nachhaltige und fruchtbare Agroforstsysteme entstehen können. Dieses Ziel wurde in drei untergeordnete Ziele unterteilt: (1) das Verständnis des Ist-Zustandes des organischen Abfallmanagements im Forschungsgebiet, (2) die Untersuchung von Modifikationsmöglichkeiten für nachhaltige Bananen-Kaffee-basierte Agrarforstsysteme sowie (3) die Evaluierung der Optimierungsmöglichkeiten des organischen Abfallmanagements zur Steigerung der landwirtschaftlichen Produktion. Für jedes Ziel wurde eine Forschungsfrage entwickelt: (1) Inwieweit werden die organischen Abfälle bereits genutzt (Ist-Zustand) und kann abgeschätzt werden, ob das momentane Abfallmanagement ausreicht, um die Bodenfruchtbarkeit und die Produktion von Nahrungsmitteln und Energieträgern zu erhöhen und damit die Armut zu reduzieren; (2) Ob und wie das derzeitige Management organischer Abfälle verbessert werden könnte, um die Bodenfruchtbarkeit und die Biomasseproduktion zu erhöhen; (3) Ob und wie negative Nährstoffbilanzen in positive umgewandelt werden können, wenn das organische Abfallmanagement in den Anbausystemen optimiert und verbessert in den landwirtschaftlichen Stoffkreislauf integriert werden würde.

Zur Beantwortung der ersten Frage wurden 150 kleinbäuerliche Haushalte zu ihrer aktuellen landwirtschaftlichen Produktion, der Verfügbarkeit und Aufbereitung von organischen Abfällen sowie deren Verwendung im Anbau der wichtigsten ein- und mehrjährigen Kulturpflanzen befragt. Dazu zählen u. a. Bananen (*Musa* L.), Kaffee (*Coffea canephora* L. var. *robusta*), Bohnen (*Phaseolus vulgaris* L.), Mais (*Zea mays* L.), Maniok (*Manihot esculenta* Crantz), Avocados (*Persea americana* L.) und Zitrusfrüchte (*Citrus* L.). Die Befragung umfasste geografische und ökonomische Daten sowie haushaltsbezogene und landwirtschaftliche Informationen in Bezug auf den Wasser-Boden-Abfall-Nexus und den Wasser-Energie-Nahrungsmittel-Nexus. Mit den erhobenen Daten wurde eine expertenbasierte Typologie der befragten Haushalte erstellt, um diese nach ihrer Biomasseproduktion sowie der Nutzung von organischen Abfällen zu kategorisieren. Bezüglich der zweiten Frage wurden fünf Fokusgruppendiskussionen mit den Ausbildern und Ausbilderinnen einer lokalen Bauernschule durchgeführt, die in den vergangenen zwei Jahrzehnten mehr als 700 kleinbäuerliche Haushalte in nachhaltiger Landwirtschaft schulten. Dabei wurde ebenfalls eine expertenbasierte Typologie der geschulten Haushalte erstellt. Beide Haushaltstypologien wurden hingehend ihrer Biomasseproduktion, organischen Abfallnutzung und Wohlstandes miteinander verglichen. Im Rahmen der dritten Fragestellung wurden die Nährstoffkreisläufe der Hausgärten von geschulten und nicht geschulten Bauernhaushalten analysiert. Dabei wurden folgende Szenarien berücksichtigt: S0: der normale Betrieb ohne Änderungen (Ist-Zustand); S1: die Nutzung von 80 % des verfügbaren menschlichen Urins; S2: die Einarbeitung von 0,5 t pro Jahr der krautigen

Leguminosenart *Crotalaria grahamiana* in den Boden; S3: die Produktion von jährlich 5 m^3 CaSa-Kompost, bestehend aus menschlichen Ausscheidungen und Biokohle, und dessen Ausbringung auf 600 m^2 in den Hausgärten; und S4: eine Kombination aus S1, S2 und S3. Entsprechende Daten wurden der Literatur entnommen.

Die Ergebnisse zeigten, dass die Einbindung organischer Abfälle auch in degradierten Bananen-Kaffee-basierten Anbausystemen noch immer eine Schlüsselrolle im Nährstoff- und Bodenfruchtbarkeitsmanagement spielt, jedoch zu einem niedrigeren Ausmaß als noch vor 50 Jahren. An Bedeutung verlor dabei auch die traditionelle Weitergabe des Wissens über Kompostierung durch erschwerte sozio-ökonomische Bedingungen. Generell wurde festgestellt, dass Kleinbauernfamilien, die organische Abfälle auf ihren Feldern ausbringen, höhere landwirtschaftliche Erträge erzielen. Das Potenzial zur Erhaltung der Bodenfruchtbarkeit wird dabei jedoch aktuell nicht vollständig ausgeschöpft, und nur ein Drittel der herkömmlichen kleinbäuerlichen Haushalte erzielt einen den Lebensumständen annähernd angemessenen Lebensunterhalt (Ist-Zustand). Zum Beispiel können diese Haushalte ihre Kinder zumindest in die staatlichen Grundschulen schicken. Ein weiteres Drittel der ungeschulten Haushalte nutzt organische Dünger zu einem geringeren Ausmaß und erzielt deswegen und wegen weiterer Schwächen im landwirtschaftlichen Management geringere Ernteerträge. Sie sind damit stärker armutsgefährdet als die erstgenannte Gruppe. Jedoch sind v. a. Haushalte, die von alleinerziehenden Frauen geführt werden (ebenfalls ein Drittel der befragten Haushalte), am stärksten von Ernährungsunsicherheit und Armut betroffen. Dabei spielen problematische, sozio-ökonomische Hintergründe eine erschwerende Rolle. Verlassene, geschiedene oder verwitwete Frauen, denen eine erneute Heirat erschwert wird, können oftmals täglich nur wenige Stunden auf ihren eigenen Feldern arbeiten, weil sie zugleich die im Haushalt mitlebenden Kinder und älteren Menschen betreuen müssen. Zudem arbeiten sie, im Versuch die Grundversorgung der Familie zu sichern, für einen geringen Lohn auf den Feldern der anderen Bauernfamilien. Damit bleiben die eigenen Felder oftmals unbestellt.

Um das Ausmaß dieser Armutsspirale zu verringern, entwickelte eine lokale Bauernschule eine umfangreiche Ausbildung im Bereich nachhaltiger Landwirtschaft. Die erfolgreiche Implementierung der Ausbildung in die eigene Produktion hat die Lebensgrundlage von mindestens einem Drittel der geschulten Bauernhaushalte deutlich verbessert. Erfolgreich umgesetztes Wissen über Boden- und Nährstoffmanagement, einschließlich der Modifikation von Kompostierungstechniken, sowie Wissen über Aufforstung, Auswahl geeigneter einheimischer Kultur- und Heilpflanzen sowie Baumarten, verbesserte Arbeitseinteilung und Zeitmanagement, die Einführung landwirtschaftlicher Buchführung sowie geschlechtergerechte Kommunikation und Entscheidungsfindung und

Rollenverteilung innerhalb der Familien haben dazu geführt, dass degradierte Bananen-Kaffee-basierte Anbausysteme sich zunehmend zu multifunktionalen Agroforstsystemen entwickeln. Hierdurch hat sich nur für ein Drittel der ausgebildeten Bauern bereits die Lage signifikant verbessert. Ein weiteres Drittel befindet sich noch in dem Transformationsprozess. Ihre Erträge bleiben jedoch unter denen der ersten Gruppe. Die dritte Gruppe innerhalb der geschulten Bauernhaushalte konnte das erworbene Wissen wiederum nicht oder nur kaum in die Praxis umsetzen. Diese Gruppe bleibt in Bezug auf Ernährungssicherheit, Einkommens-diversifizierung und Zugang zu Bildung stark vulnerabel. Die Anlayse zeigte auch, dass in allen drei erwähnten geschulten Haushaltsgruppen, die von Frauen geführten Haushalte einen ungefähr gleichen Anteil ausmachen.

Im Vergleich der Nährstoffbilanzen der Hausgärten zwischen den geschulten und den ungeschulten Bauernhaushalten zeigen erstere eher eine positive Nährstoffbilanz aufweisen als letztere. Obwohl sich die Nährstoffbilanz der Felder ungeschulter Haushalte unter allen Managementszenarien verbessern würden, würde sie jedoch immer noch negativ bleiben, insbesondere für Stickstoff. Außerdem stellt die unzureichende Behandlung der organischen Abfälle, v. a. die von Tierdung und menschlichen Exkrementen, eine potenzielle Gesundheitsgefahr für Mensch und Tier dar. Darüber hinaus sind die Nährstoffkreisläufe in den Hausgärten aller Familien nicht geschlossen, da ein Großteil der Nährstoffe aus der Umgebung importiert wird, z. B. durch die Verwendung von Futtermittel aus dem umliegenden Grasland. So degradiert das umliegende Grasland weiterhin durch Überweidung. Ebenso ist Brennholz weiterhin ein knappe Ressource, die weiterhin oftmals vom umliegenden Waldland gesammelt wird. Um diese Abhängigkeit zu überwinden, könnten kurzfristige Nährstoffdefizite in den Böden der Hausgärten durch eine zusätzliche gezielte Ausbringung von Mineraldünger gemildert werden. Zudem könnte Solarenergie stärker genutzt werden. Allerdings stellen der begrenzte Zugang zu Mineraldünger und Technologien, die arbeitsintensive Herstellung von Kompost vor dem Hintergrund der Landknappheit, Arbeitskräftemangel, durch den Klimawandel länger werdenden Trockenzeiten und sozio-ökonomischen Ungleichgewichten große Herausforderungen dar.

Handlungsbedarf bezüglich unterstützender Richtlinien und Vorschriften besteht z. B. zur sicheren und effizienten Nutzung von organischen Abfällen und Abwässern in der kleinbäuerlichen Landwirtschaft. Die ganzheitlichen Ansätze des Wasser-Energie-Nahrungsmittel- und des Wasser-Boden-Abfall-Nexus könnten dabei unterstützend wirken. Wichtige Ziele für eine Nachhaltige Entwicklung der Vereinten Nationen sind das Ziel 2 (Kein Hunger), Ziel 7 (Bezahlbare und saubere Energie) und Ziel 15 (Leben auf dem Land). Keiner der ungeschulten Kleinbauernhaushalte lebt derzeit unter den Bedingungen, die diese Ziele vorgeben. Nur ein Drittel der geschulten Bauernhaushalte, die das Training erfolgreich umgesetzt haben, ist der Erreichung dieser Ziele einen Schritt näher gekommen. Um dieser Entwicklung entgegenzuwirken, könnte u. a. eine Roadmap als Ausgangspunkt für zukünftige Initiativen zur Entwicklung kohärenter Politiken und wissenschaftlich fundierter Richtlinien entwickelt werden. Auch für die Entwicklung wissenschaftsbasierter Richtlinien ist die Förderung von Forschungsprogrammen zukunftweisend, z. B. durch die Vergabe von Forschungsgenehmigungen an internationale Forschungseinrichtungen, welche mit der Regierung entsprechende Politikempfehlungen ausarbeiten und damit den Transfer wissenschaftlicher Erkenntnisse in die Praxis fördern könnten.

1 Introduction

1.1 Problem identification and structure of this thesis

East Africa has experienced rapid population growth since the 1960s. Today, it is the fastest-growing region in Africa, with an average annual population growth rate of 6.7% between 2013 and 2017 (Economic Commission of Africa 2018). More than 75% of the growing population is fed by the yields of smallholder agriculture (Salami *et al.* 2010). In rural areas it is often more than 90%. The local population depends on the food and wood production in this region. Common staple crops are the East African Highland Banana (EAHB-AAA) and other banana cultivars (*Musa* L. spp.). Bananas and plantains are densely grown alongside coffee (*Coffea* L. spp.) in smallholder banana-coffee-based farming systems (*cf.* Baijukya and Steenhuijsen Piters 1998). These farming systems consist of four components: the older and younger homegardens (*kibanja* and *kikamba* in the local Bantu language), woodland (*kabira*) and grassland (*rweya*) (*cf.* Baijukya 2004; Copeland Reining 1967). In these agroforestry systems, the perennial crops (banana, coffee) are traditionally cultivated together with trees in whose shade livestock is kept and annual food crops grow, such as beans (*Phaseolus vulgaris* L. and other spp.), maize (*Zea mays* L. and other spp.), and cassava (*Manihot esculenta* Crantz and other spp.) (Baijukya 2004; Garrity *et al.* 2012). Firewood and self-produced charcoal are still the main energy sources for cooking (Othieno and Awange 2016). However, in large areas of the Lake Victoria region, population growth and environmental degradation have led to small farm sizes and declining crop yields.

Studying the scientific contributions of Copeland Reining (1967), Katoke (1970), and Touber and Kanani (1996) allows the conclusion that organic farm waste management has had an essential function in maintaining fertile farming systems for many centuries, even if the terms composting, farm waste management, circular economy, and multifunctionality were not yet used. Copeland Reining (1967), for instance, reported extensively on the use of organic farm waste, especially the use of banana leaves, e.g., as plates or storage hulls, and how ultimately all organic matter was returned to the soil at the end of its use phase via composting. As a result, banana-coffee-based farming systems in the Lake Victoria region were diverse and fertile until a few decades ago. The use of organic farm waste as soil conditioner and fertiliser has a long tradition in these farming systems. However, for several decades, the withdrawal of nutrients from crop and wood production has been higher than the return of nutrients from organic farm waste used as compost (Henao and Baanante 2006).

Farm nutrient management is essential to maintain soil fertility and food production, to decrease poverty, and to ensure the continuance of ecosystem services (Adhikari and

Hartemink 2016; Bekunda *et al.* 2005; Mueller *et al.* 2012). Besides, adapting agriculture to climate change also has a positive long-term impact on crop yields and food security. Therefore, in this thesis, the integration of organic farm waste management into the biomass production of degraded smallholder banana-coffee-based farming systems has been studied. The study area is located in the remote Kagera region in NW Tanzania, bordering with Lake Victoria in the east. The economy in the region is dominated by smallholder agriculture. The export of bananas and coffee from this region is essential for Tanzania (URT 2012, 2016). Food security is low in this region and agricultural production per capita has declined since the late 1980s, although organic farm waste has been a common organic fertiliser in these farming systems. Increased crop production is necessary to feed the rural and peri-urban population in the study area and to continue the export of bananas and coffee. The diverse farming systems and nature are dominated by severe environmental degradation caused by complex social and economic challenges, which are further described in chapter 2. Besides, the Kagera region has been struggling with the consequences of HIV and AIDS since the 1980s, and the influx of hundreds of thousands of refugees since the 1990s (Alix-Garcia and Saah 2010; Lwihula *et al.* 1993). The negative impact of the AIDS pandemic on household and community welfare was severe, with declining production as labour was reallocated to nurse and mourn the victims (Tibaijuka 1997). Agricultural productivity also fell when assets and working capital had to be sold to pay medical bills, and the burden on dependents increased dramatically (*ibid.*). In addition, the refugee influx accelerated the demand for food, drinking water, and firewood (Berry 2008). Deforestation and degradation of vegetation, soil and water resources accelerated, and therefore led to conflicts in land-use and labour markets between refugees and local communities (Berry 2008; Musoke 1997).

To assess the status of soil fertility in a defined area, scientists often use the soil nutrient balance (SNB) as an indicator. SNB is defined as the difference between the sum of nutrient inputs entering the soil and the sum of the nutrients leaving the soil at a specific scale, such as at the farm level (Cobo *et al.* 2010; Kiboi *et al.* 2019; Stoorvogel and Smaling 1990). Nutrient balances (NBs) can be also determined for a whole farming system in which soil is one component. Positive balances indicate a nutrient stock in the system, while negative balances indicate a nutrient deficiency. NBs in banana-coffee-based farming systems in East Africa are often negative under poor management and with increasing distance from the farmhouse (Baijukya and Steenhuijsen Piters 1998; Henao and Baanante 2006; Kiboi *et al.* 2019; Stoorvogel and Smaling 1990). They vary with the scale and the nutrient inflows and outflows under consideration, e.g., for nitrogen (N) from -76 kg N ha^{-1} to +20 kg N ha^{-1} (Kiboi *et al.* 2019). NBs are particularly negative in areas where harsh environmental conditions, constant farming, omitted fallow periods, and a lack of organic and mineral fertilisers have diminished soil nutrient stocks over decades. As a result, insufficient or no fertilisation of already depleted soils endangers agricultural production, and diminishes the prosperity of smallholder families who remain trapped in poverty (Franke *et al.* 2019; Hillocks 2014; Mkonda and He 2018; Smaling and Braun 2008; Tittonell and Giller 2013). The impact of climate change worsens the situation. Farmers have barely adapted to climate change, if at all. For the farmers, climate change is particularly noticeable in the form of late and intermittent rainfall during the rainy seasons, as well as prolonged dry seasons (FAO 2017; Gebrechorkos *et al.* 2018a).

This thesis aims to investigate the current use of organic waste and to assess whether the components of organic waste, when optimally used, are sufficient to restore soil fertility and thus the productivity of banana-coffee-based farming systems. The study area is characterised in chapter 1.2, the objectives of this research are given in chapter 1.3, and the resulting research questions are specified in chapter 1.4. In the same chapter, research gaps, theoretical background, and the methodology applied are summarised. All publications are listed in chapter 1.5. The methodology and study area are also described in depth in three journal articles and one book chapter, which have been published in the context of this thesis (chapters 2, 3, 4, and 5). Collected data are presented in the appendix (from page 233 onwards). In the synthesis (chapter 6), the main findings of this thesis are summarised and subject to a comprehensive discussion. The findings are further discussed in the broader scope of the Sustainable Development Goals (SDGs). Recommendations for action and policy development – regarding the restoration of degraded agroforestry systems and the promotion of composting in agriculture – for the Ministry of Agriculture and the National Land Use Planning Commission in Tanzania (NLUPC) are derived. Finally, limitations of this research are offered for discussion in chapter 6.4, and final conclusions are drawn.

1.2 Study area

1.2.1 Environment

Location

The study area is the hilly, tropical Kagera region in NW Tanzania (Fig. 1-1), where banana-coffee-based farming systems have a long tradition. It is located at 1.0° to 2.1°S and 30.4° to 31.4°E and covers eight wards (a ward is an administration unit) in the Karagwe district (Bugene, Chanika, Chonyonyo, Ihanda, Kihanga, Kituntu, Ndama, and Nyakahanga) and eight wards in the Kyerwa district (Isingiro, Kamuli, Kimuli, Kikukuru, Mabira, Nkwenda, Rukuraijo, and Rwabwere).

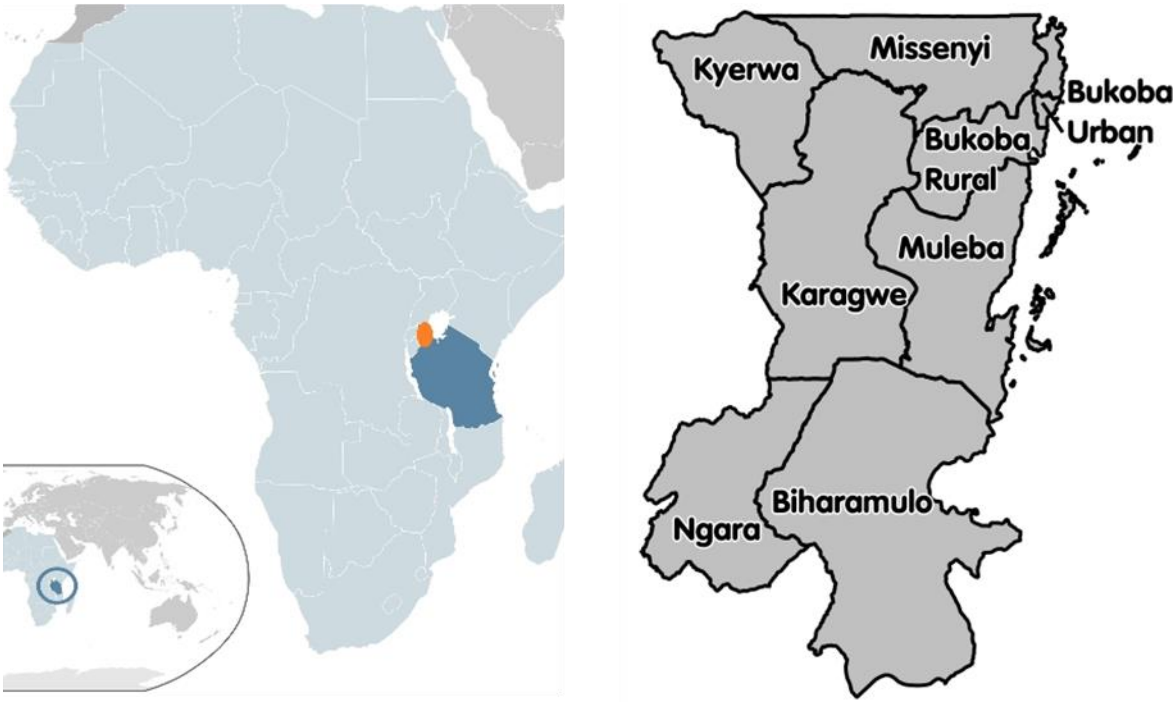


Fig. 1-1: The map on the left shows Tanzania in blue and the Kagera region in orange (Map Library 2007). The right-hand map depicts the Kagera region and its districts (Common Wikimedia 2016).

Precipitation

The study area is characterised by a bimodal rain pattern, two corresponding cropping seasons, annual precipitation of 982 mm (± 127 mm), and moderate temperatures, with minimum mean temperatures between 12°C and 16°C and maximum between 25°C and 28°C (TMA 2017; Touber and Kanani 1996). The rain falls in two rainy seasons, the *Masika* and *Vuli*, with rainfall decreasing in quantity from the shore of Lake Victoria in the east to the mountains in the Karagwe-Ankolean System in the west (Fig. 1-2).

Geology

The hilly terrain belongs to the highlands of the East African Rift, with altitudes between 1,200 and 1,650 m above sea level (asl) (Fig. 1-3) (FAO 2010a, 2010b). The 400- to 600-million-year-old geogenic parent material (Pre-Cambrian) consisted of meta-sedimentary rocks and went through five geological eras until the Karagwe-Ankolean System was formed (Fig. 1-4) (Ndege *et al.* 1995). During thermal metamorphism, shales, phyllites, schists, quartzites, sandstone, and conglomerates were intensely folded and faulted (Fig. 1-5). Based on this geology, subsequent geomorphological processes had caused today's hilly landscape of the study area and changed the course of the Kagera River, leading it into Lake Victoria (FAO and UNESCO 1977; Ndege et al. 1995).

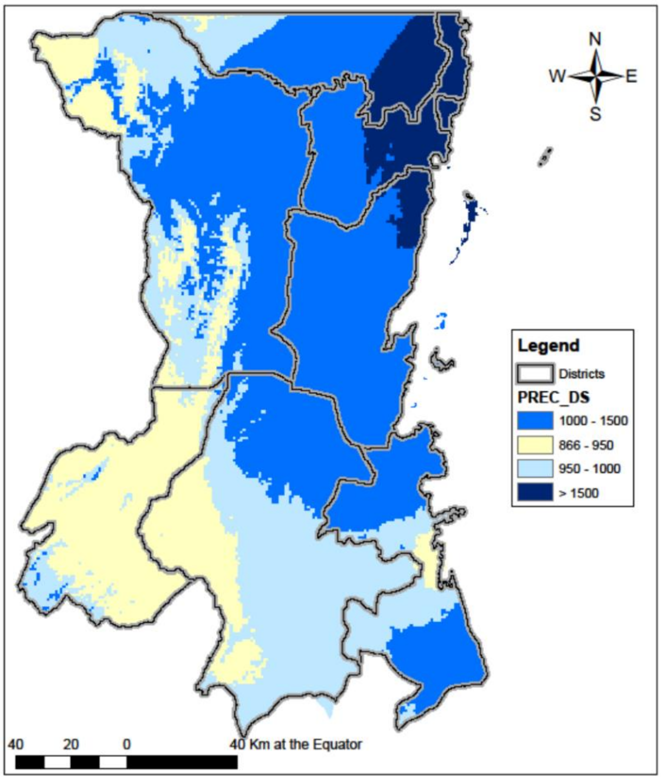
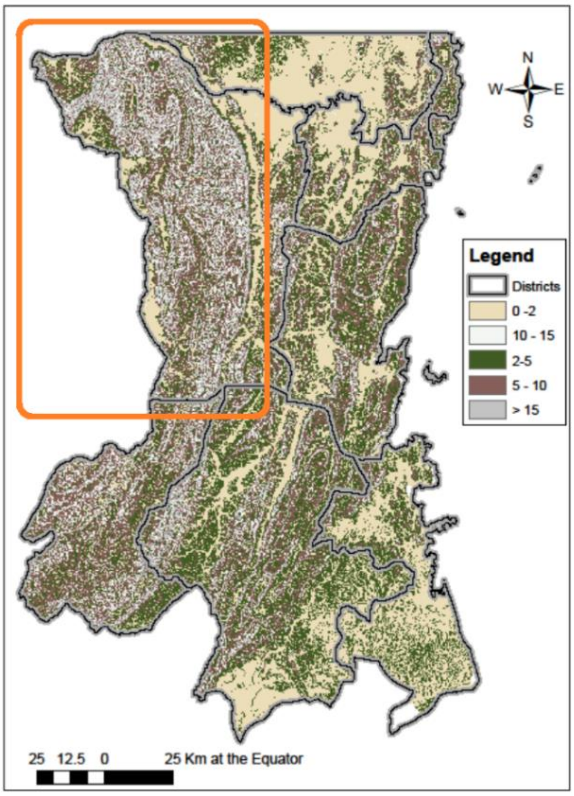


Fig. 1-2: Annual rainfall distribution in the Kagera region (FAO 2010b).



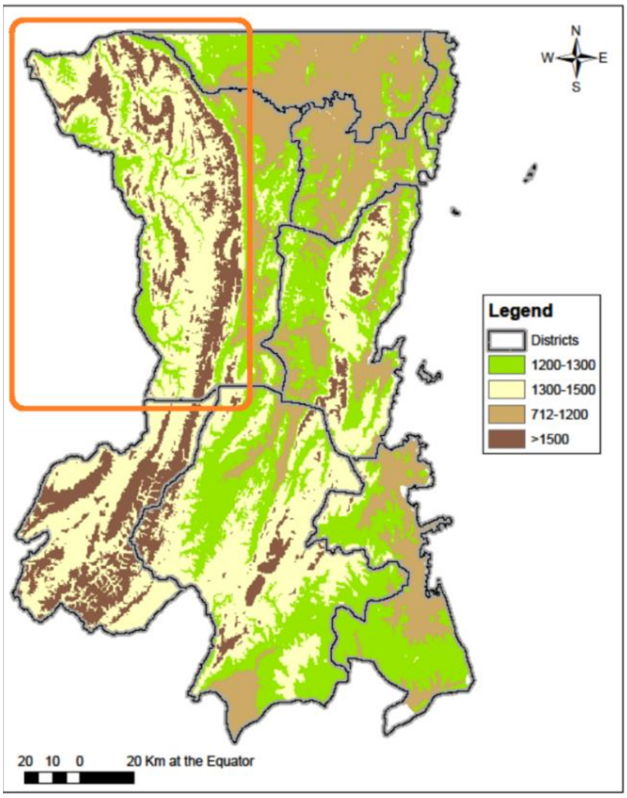


Fig. 1-3: The map on the left right depicts the slope gradient in per cent in the Kagera region, and the map on the shows the altitude in m asl (FAO 2010a, 2010b).

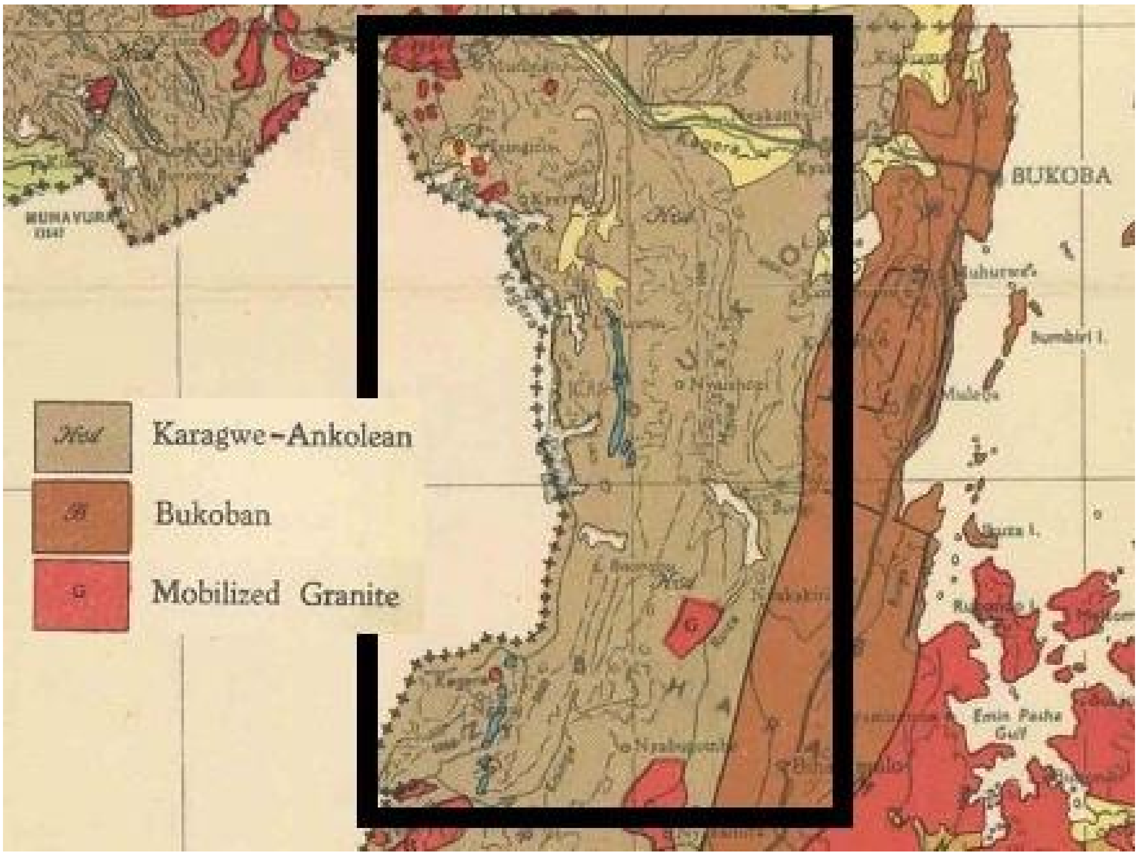


Fig. 1-4: Geology of the Kagera region (Department of Lands and Surveys 1952).

As Figures 1-3 to 1-5 show, the folding processes followed a distinctive north-south direction, with ridges running from north to south and steep slopes in the western and eastern directions (Department of Lands and Surveys 1952; FAO 2010a, 2010b; Ndege et al. 1995; Touber and Kanani 1996).

Soils and agro-climatic zones

In the study area, current small-scale soil data is scarce. Scientists mapped the soils near Lake Victoria already in the 1930s, e.g., Milne (1936) and described them as follows: *"The red earth on the shales of the Karagwe-Ankolean System is in brown colour rather than red, have a very low lime status and high acidity with a relatively high organic matter content even at some depths of the profile, and are markedly heavier than the corresponding soils on gneiss."* Today, through the achievements of remote sensing, global digital mapping of soils and their chemical and physical properties is possible. These maps are often validated by soil samples and made available as open-source, e.g., on the websites maps.isric.org, africasoils.net, and soilgrid.org. Fig. 1-6 shows a section of the soil map from soilgrids.org (SoilGrids 2021). *Acrisols*, *Ferralsols*, and *Cambisols* are the most probable soil types in the study area (*ibid.*). However, this map only gives a probability for the occurrence of the soil types within a 250 m grid.

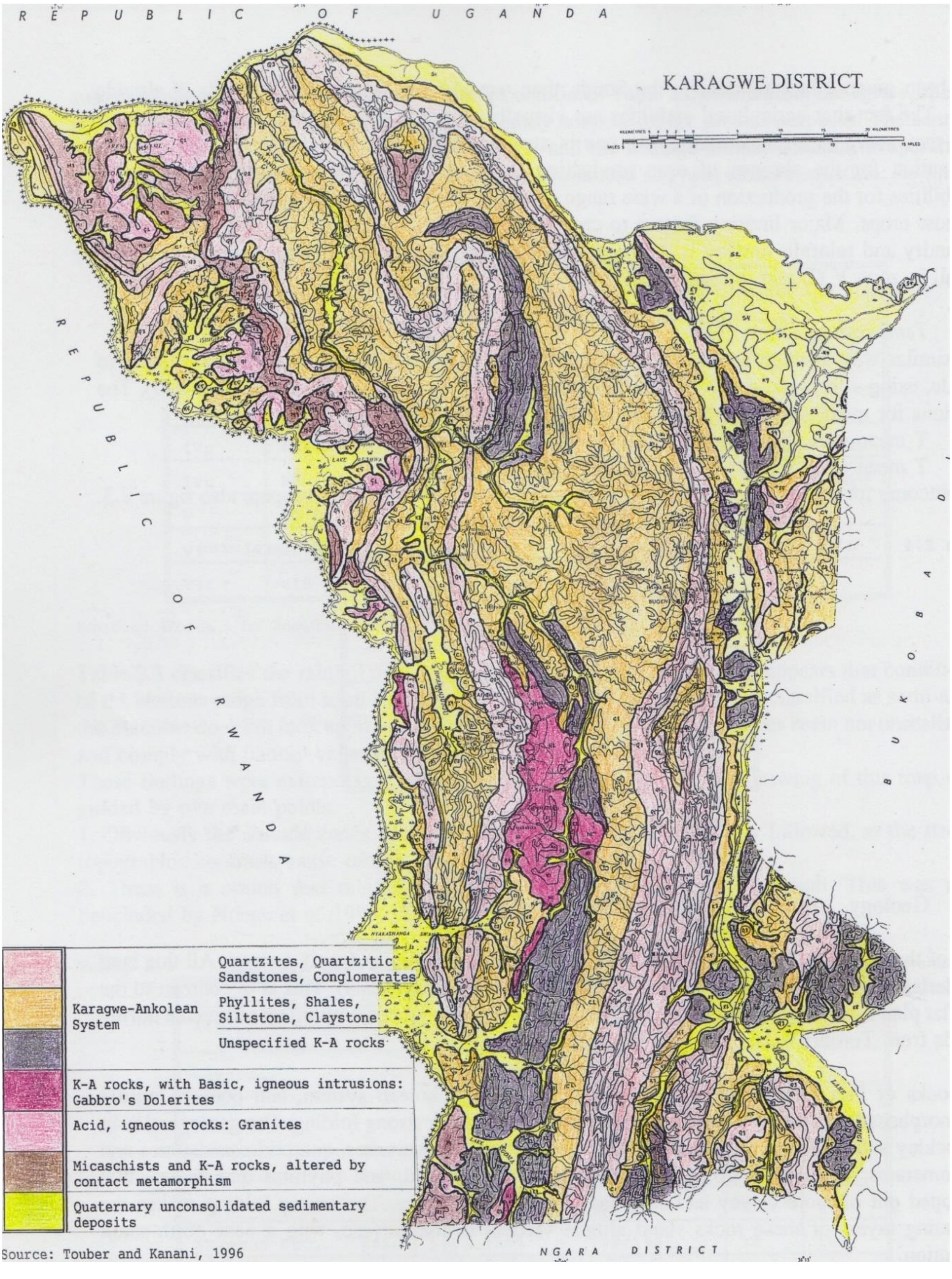


Fig. 1-5: Distribution of rock types in the Karagwe and Kyerwa districts (Touber and Kanani 1996).

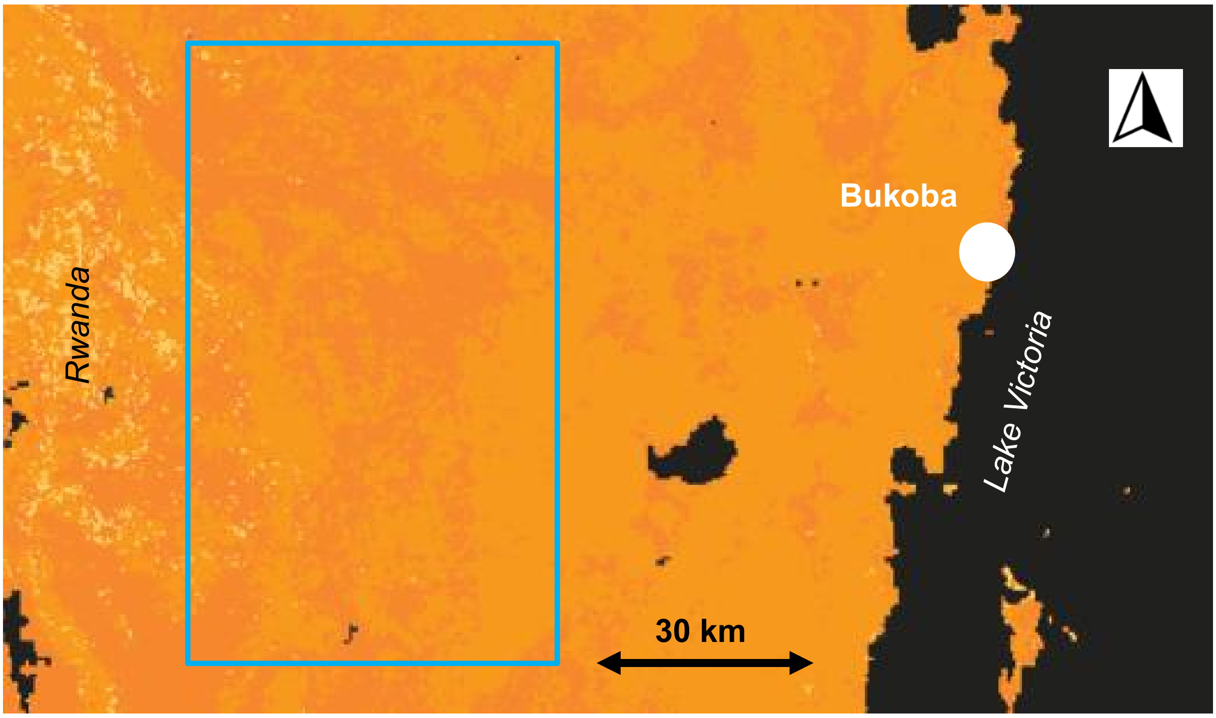


Fig. 1-6: Classification of soil types in the Kyerwa and Karagwe districts (blue) in the east of the Lake Viktoria (black) according to the World Reference Base (FAO 2006). Light orange indicates that Acrisols, dark orange that Ferralsols, and yellow that Cambisols are likely to predominate (SoilGrids 2021). Note by the author: The colouring of individual soil types was not changeable.

In the 1990s, after the population density had increased enormously (*cf.* Fig. 3-9 at page 105), detailed small-scale soil mapping was carried out in the Kagera region, e.g., by Ndege *et al.* (1995) and Touber and Kanani (1996). The researcher showed that soil types vary on a small scale from a few metres to several tens of metres depending on the amount of precipitation, the altitude and slope gradient, and geology. According to the FAO-UNESCO soil classification system from 1988, they classified soils along the hills as *Ferralsols*, *Leptosols*, *Acrisols*, *Cambisols*, and *Phaeozems*; in river terraces as *Fluvisols*, *Gleysols*, and *Planosols*; and in swamps as *Histosols*. Ndege *et al.* (1995) also described soil characteristics in relation to the ability to be used as agricultural soils. Soils on slopes are often gravelly, shallow, and prone to erosion; soils on ridges are suitable for agriculture if they are deep enough and not too gravelly, being dominated by sandy loam and clay loam textures, moderately deep, well drained, and reddish-brown to brown; soils at the foot of slopes or in the valleys are the most suitable for agriculture due to their depth and high water storage capacity (*ibid.*). More recently, Krause *et al.* (2016) investigated *Andosols* as a further predominant soil type in the study area. *Andosols* are common in high-altitude tropical areas, are suitable for crop production, especially for coffee and banana, when phosphorus (P) is frequently added, have low bulk density, low base saturation, strong phosphorus retention (P), high pore volume, a tendency to form microaggregates and pronounced shrinkage, and high level of available water and concentrations of aluminum (Al), iron (Fe) and silicon (Si) (*ibid.*).

When soils developed on slopes with a gradient below 10% (*cf.* Fig. 1-3), on rocks of the Karagwe-Ankolean systems at altitudes above 1,300 m asl (*cf.* Fig. 1-5), where annual rainfall varies between 950 to 1,500 mm (*cf.* Fig. 1-2) and the ratio between rainfall and evaporation is between 45% and 65% (Fig. 1-7), soils are best suited for agriculture (Fig. 1-8) according to the maps of Touber and Kanani (1996). Besides, soil organic carbon stocks in the study area are below 100 t ha^{-1} (Fig. 1-9), and nitrogen (N) content within the first 5 cm depth varies between 100 and 320 cg kg^{-1} (Fig. 1-10), decreasing with depth.

1.2.2 History and development of agriculture

According to the fossil record, the first hunters and gatherers arrived in the study area 500,000 years ago, while the first evidence of agricultural settlement dates back only 1,000 years ago and has been attributed to Bantu-speaking farmers (Katoke 1970). Since then, several ethnic groups crossed, settled, left, and resettled in the region now known as Karagwe and Kyerwa districts. Among these were Bantu, Nilotic (who now live in Sudan), Hamitic, and Bachwezi and Bahima people (who have since settled in Ethiopia) (*ibid.*).

In the 14th century, the Bantu-speaking Banyamboo formed patriarchal and exogamous clans. These clans first formed villages, then larger communities, and finally expanded outwards to form the Karagwe Kingdom in order to explore new agricultural land (Katoke 1970). These first farmers cultivated sorghum, eleusine, millet, and yams as staple crops and were able to manufacture pottery and iron farming tools (*ibid.*).

At the end of the 15th century and the beginning of the 16th century, Bachwezi and Bahima people conquered Karagwe. Since then, pastoralism from the Bahima, who lived on the plains, mixed with arable farming from the Bantu Banyamboo, who preferred to stay on the hills (*ibid.*). Mixed farming and a flowering trade and barter system developed in which banana seeds (*entembe* in the local Bantu language) were used as currency. Between 1500 and 1800, Karagwe's territory grew to a huge interlacustrine region and political institutions developed further (Katoke 1970). Meanwhile, its economic growth led to peaceful prosperity, while coastal goods such as copper, salt, knives, pepper, mangoes, and oranges reached Karagwe (*ibid.*). At that time, the Lacustrine Bantu comprised of eleven peoples: the Ganda, Soga, Nyoro, Toro and Ankole in Uganda, the Rwanda and Burundi peoples, the coastal Haya and Nyambo-Haya in Karagwe, and the Ha and Zinza of Tanzania (Fig. 1-11) (Copeland Reining 1967).

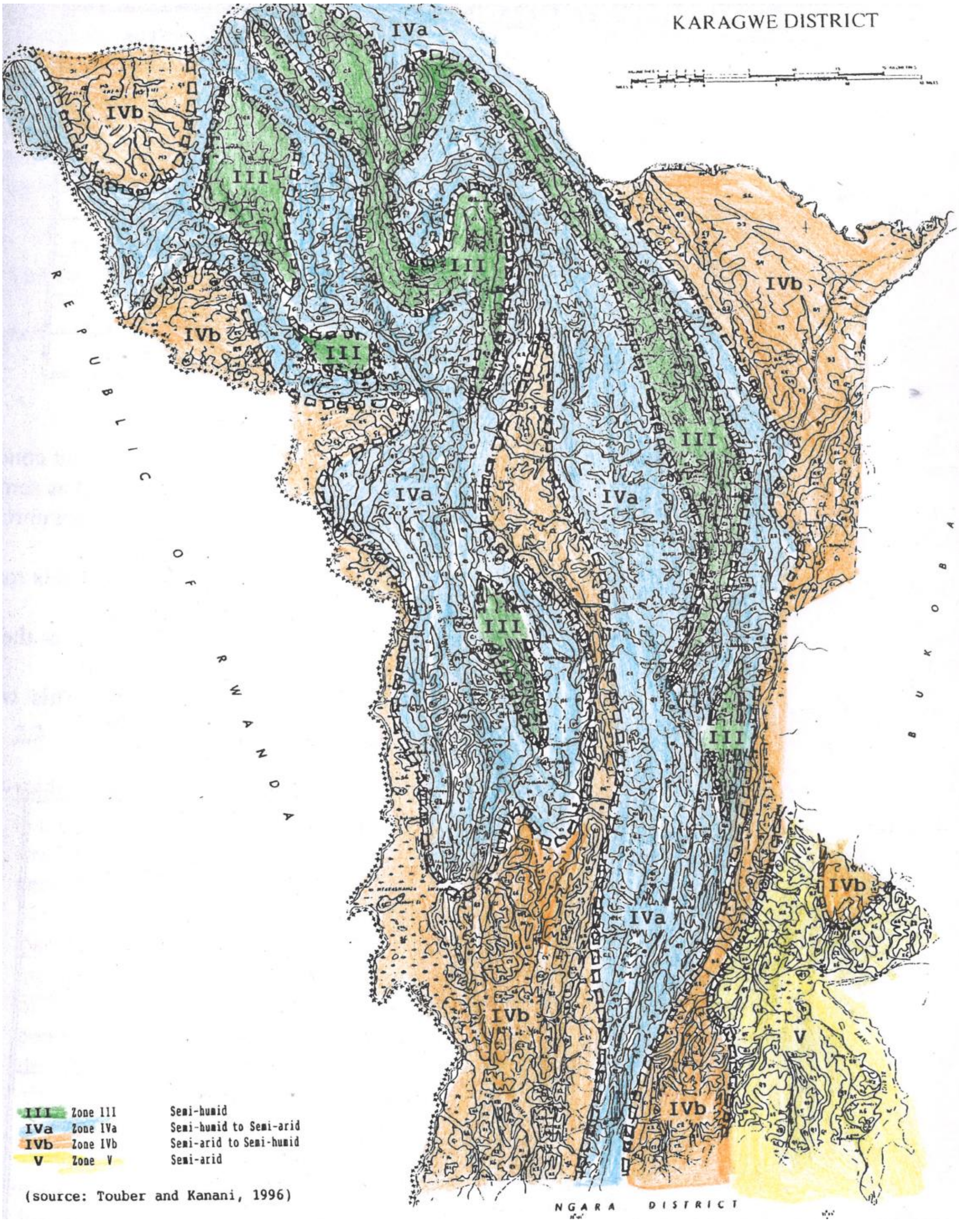


Fig. 1-7: Agro-climatic zones of the former Karagwe district. Zone III: semi-humid, 235 to 290 growing days, and an r-E ratio between 52 and 65% (annual average rainfall (r) and average annual potential evaporation (E)). Zone IVa: semi-humid to semi-arid, 205 to 235 growing days, and an r-E ratio of 45 to 52%. Zone IVb: semi-arid to semi-humid, 175 to 205 growing days, and an r-E ratio of 38 to 45%. Zone V: semi-arid, 110 to 175 growing days, and an r-E ratio of 25 to 38% (Touber and Kanani 1996).

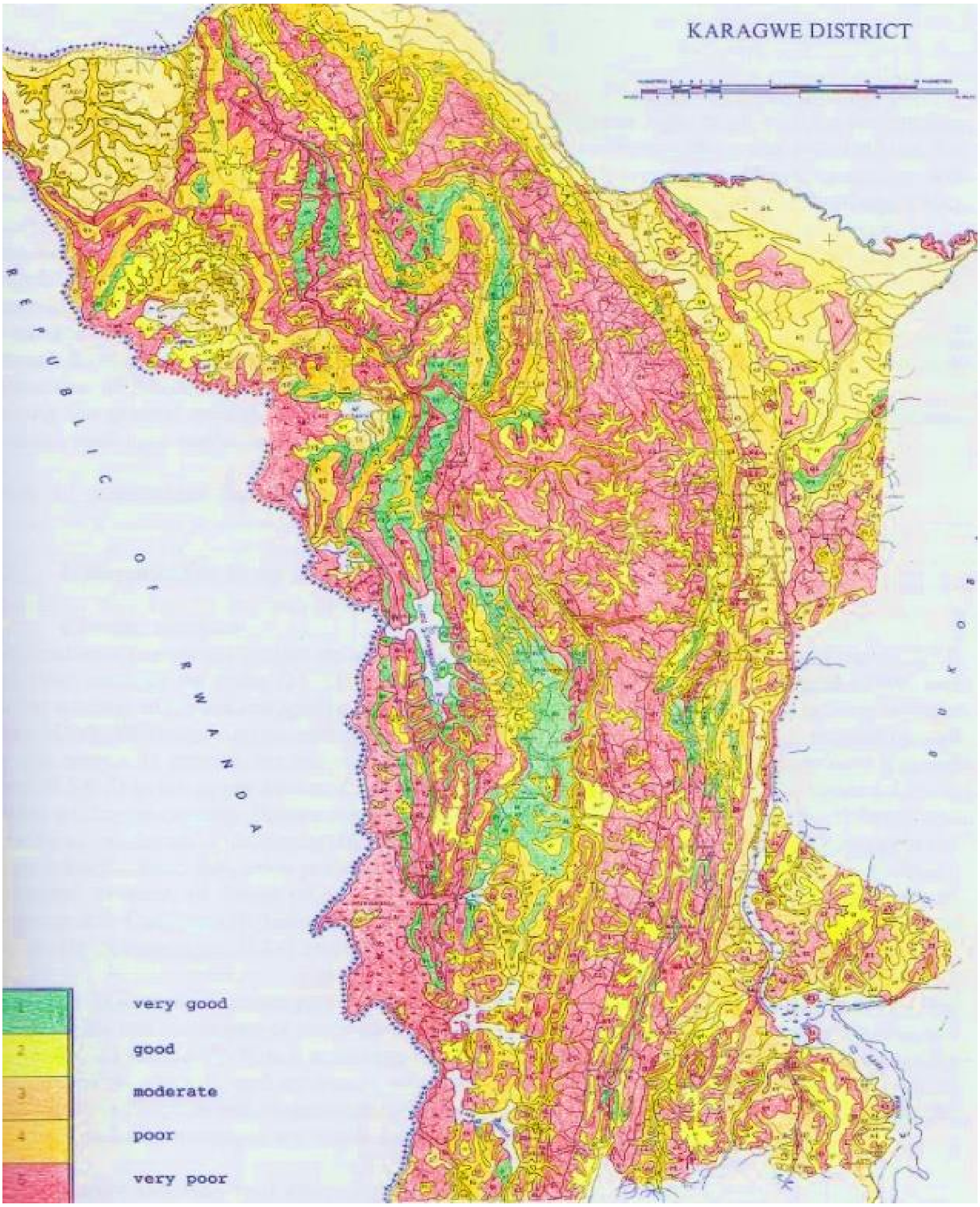


Fig. 1-8: Rating of physical soil properties in the Karagwe district according to the agroecological zones presented in Fig. 1-7. The figure considers drainage (excessively, well, moderately well, imperfectly, poorly, or very poorly drained; oxygen availability: very poor to very good), rooting space (very deep = >100 cm, deep = 60-80 cm, moderately deep = 40-60 cm, shallow = 20-40 cm, very shallow = <20 cm), water holding capacity (1 = >200 mm, 2 = 150-200 mm, 3 = 100-150 mm, 4 = 50-100 mm, 5 = <100 mm), infiltration rate (1 = low percentage runoff loss of rain, 5 = very high percentage), and erosion status (1 = not affected by human-induced accelerated erosion, 5 = strongly affected by human-induced accelerated erosion) (Touber and Kanani 1996).

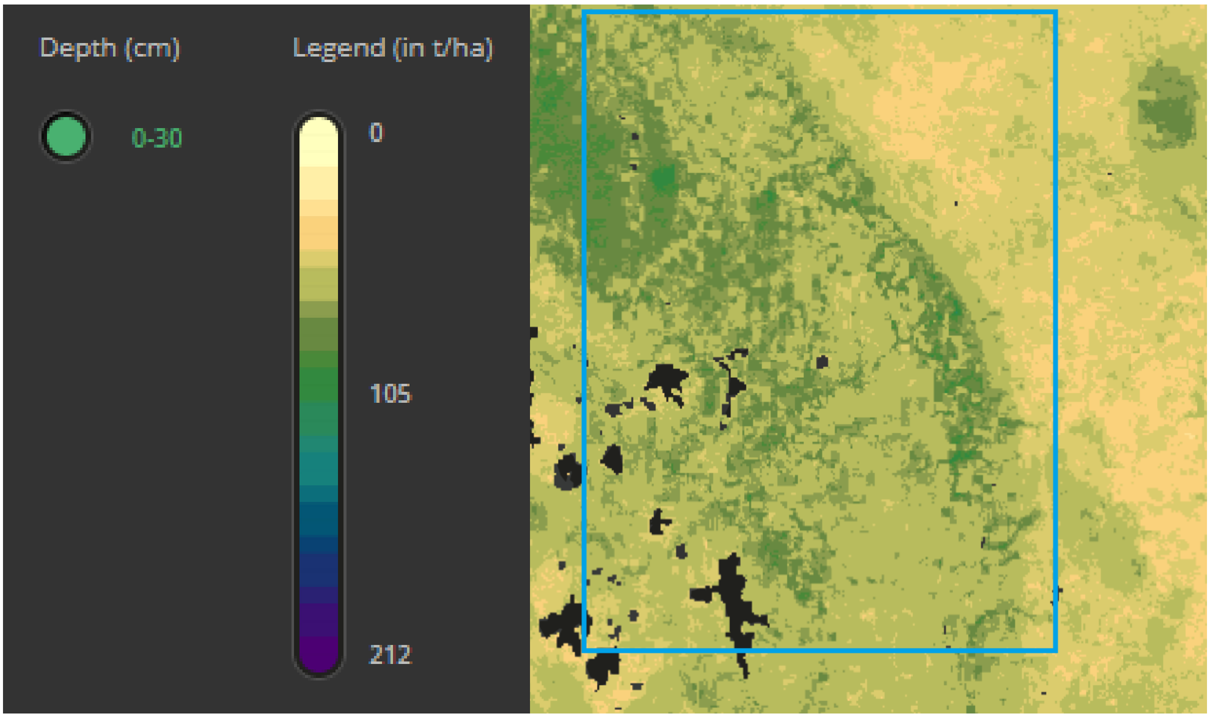


Fig. 1-9: Soil organic carbon stocks of the study area in the first 30 cm below ground varying between 30 and 100 tonnes per hectare (SoilGrids 2021). Note by the author: The colouring was not changeable.

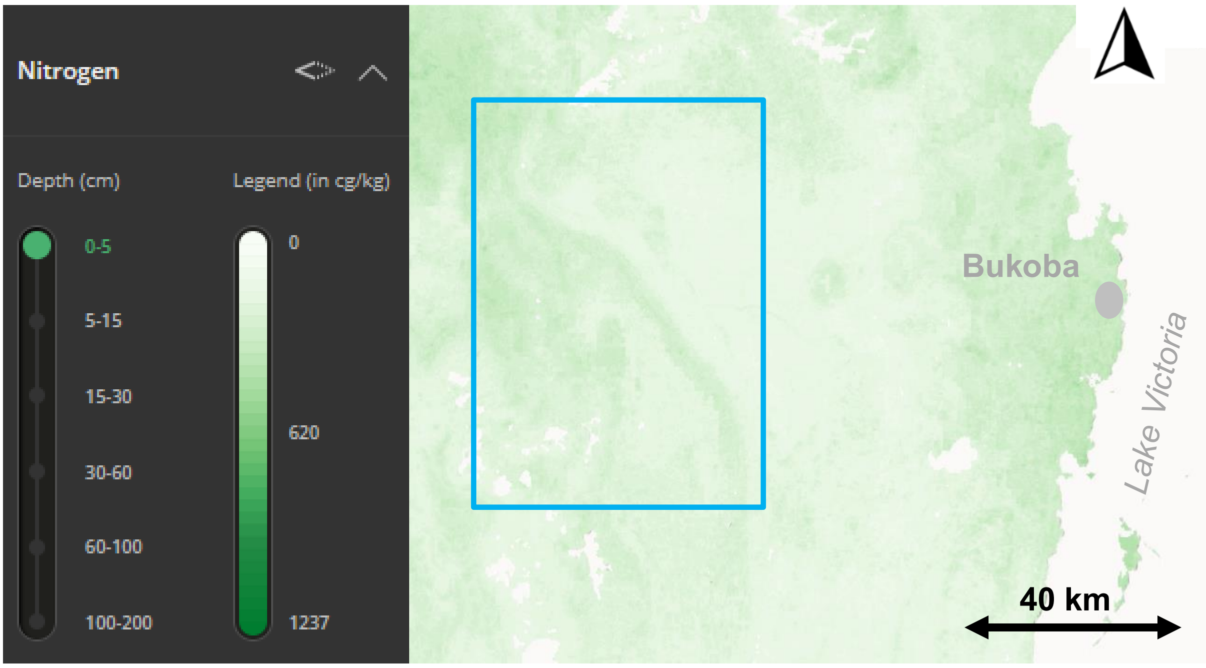


Fig. 1-10: Nitrogen content in 5 cm below ground in the study area (blue) varying between 100 and 320 centigrams per kilogram (SoilGrids 2021). Note by the author: The colouring was not changeable.

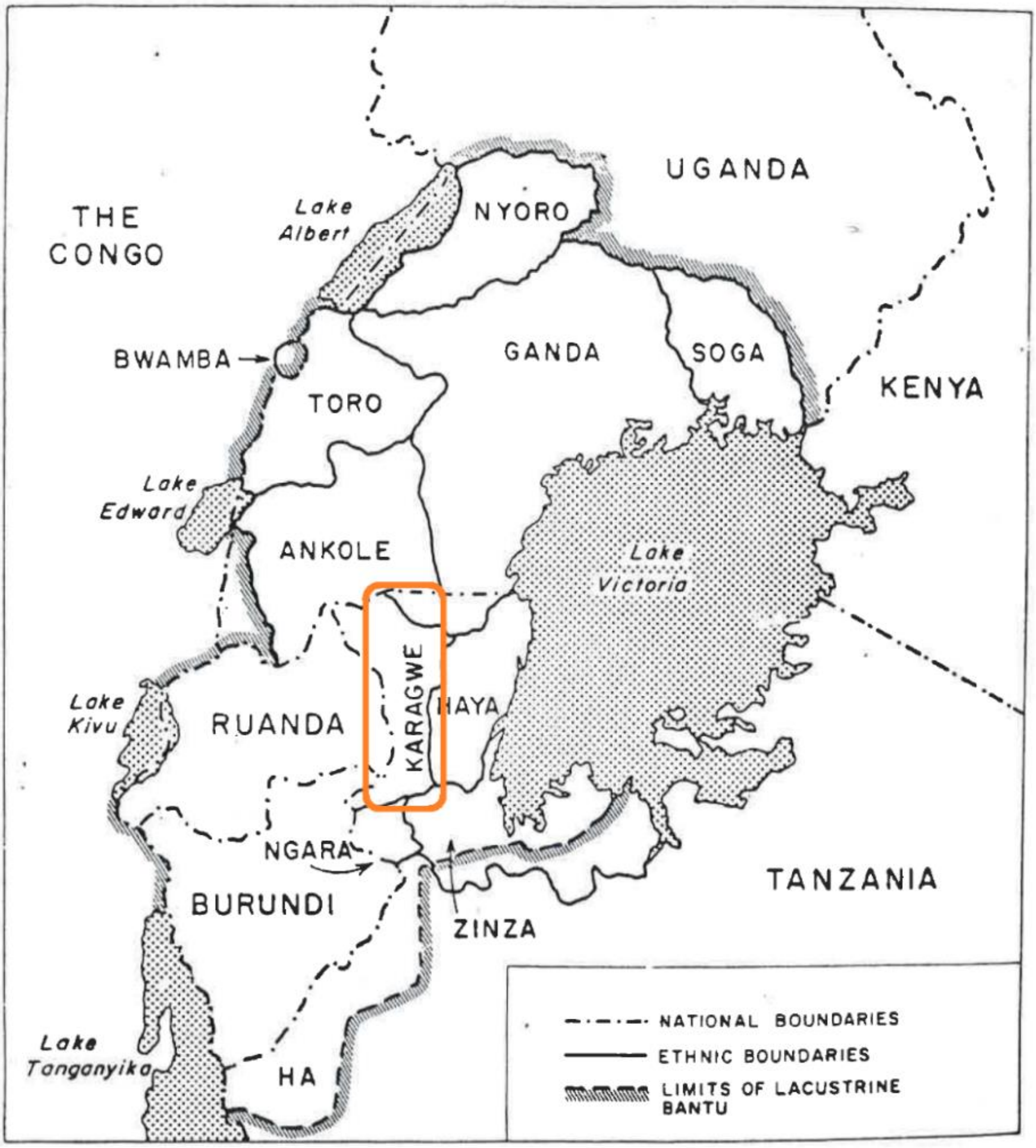


Fig. 1-11: Map of the Lacustrine Bantu-speaking people showing the Karagwe Kingdom at the beginning of the 19th century (Copeland Reining 1967).

To a certain degree, the coastal Haya and the Nyambo-Haya shared similarities in language, culture, hierarchical structure, and political organisation, and were engaged in smallholder farming with eleusine and plantain as staple crops, alongside livestock-keeping (Copeland Reining 1967).

From the late 1830s, Arab and Kiswahili traders influenced the kingdom's economy and introduced cowries (*ensimbi*) as the new currency and coffee, sweet bananas, maize, pawpaw, vegetables, and citrus fruits as new food crops (Katoke 1970). The first Europeans, John Speke and James Grant, entered Karagwe in 1860 to search for the source of the Nile, and Henry Stanley followed in 1876 (*ibid.*). Their writings predominantly shaped the European view of what they called "Darkest Africa" and effectively encouraged slavery (*ibid.*). However, at the end of the 19th century, internal conflicts between the despots, the resulting wars, and recently introduced epidemics (rinderpest, smallpox) led to the fall of the Karagwe Kingdom (*ibid.*). After the extinction of the kingdom, Germany colonised the mainland of Tanzania in 1885, as did Great Britain in 1918, both nations in turn influencing governing structures, religious faith, and fostering the linguistic enforcement of Kiswahili with the Latin alphabet rather than Arabic (Young 2002). The Nyambo-Haya is still the most abundant local tribe, and its traditions determine local agriculture to this day (Copeland Reining 1967; Katoke 1970; *cf.* Reetsch *et al.* 2020a).

Although African people represented the majority of the population throughout history, Europeans and Asians started to play major roles in their politics and economy, while Africans kept farmers, workers, or minor state agents (Copeland Reining 1967). By 1960, Europe's political hegemony ended through decolonisation, and after some years of racial disputes, Julius Nyerere became president in 1961 (Young 2002). As the founder of African socialism in Tanzania (*Ujaama*) Nyerere unified the nation by ending racial segregation and introducing Kiswahili as the national language, but, despite his popularity as a national leader, he failed to boost the national economy (Young 2002) and forced the nomadic part of the population to settle in villages between 1971 and 1975 (Bjerk 2010). Even now, the consequences of villagisation (*Vijiji*) can still be felt in several land-use conflicts, especially between farmers and pastoralists due to a shortage of grazing land in several regions of Tanzania (Kisoza 2014). In the Kagera region, land-use conflicts are currently accelerating between farmers and pastoralists, farmers and other farmers, and farmers and investors, as well as between farmers and governmental institutes because recently introduced policies favour the transformation of communal land into commercial land (*ibid.*).

Banana-coffee-based farming systems

On densely populated and steep slopes, small farmers cultivate banana-coffee-based farming systems in rainfed agriculture under semi-humid conditions. As mentioned at the beginning, banana-coffee-based farming systems consist of four components: the older and younger homegardens (*kibanja* and *kikamba* in the local Bantu language), woodland (*kabira*) and grassland (*rweya*) (*cf.* Baijukya 2004; Copeland Reining 1967). The homegarden is the core of this system, where the farmhouse is located (Fig. 1-12).

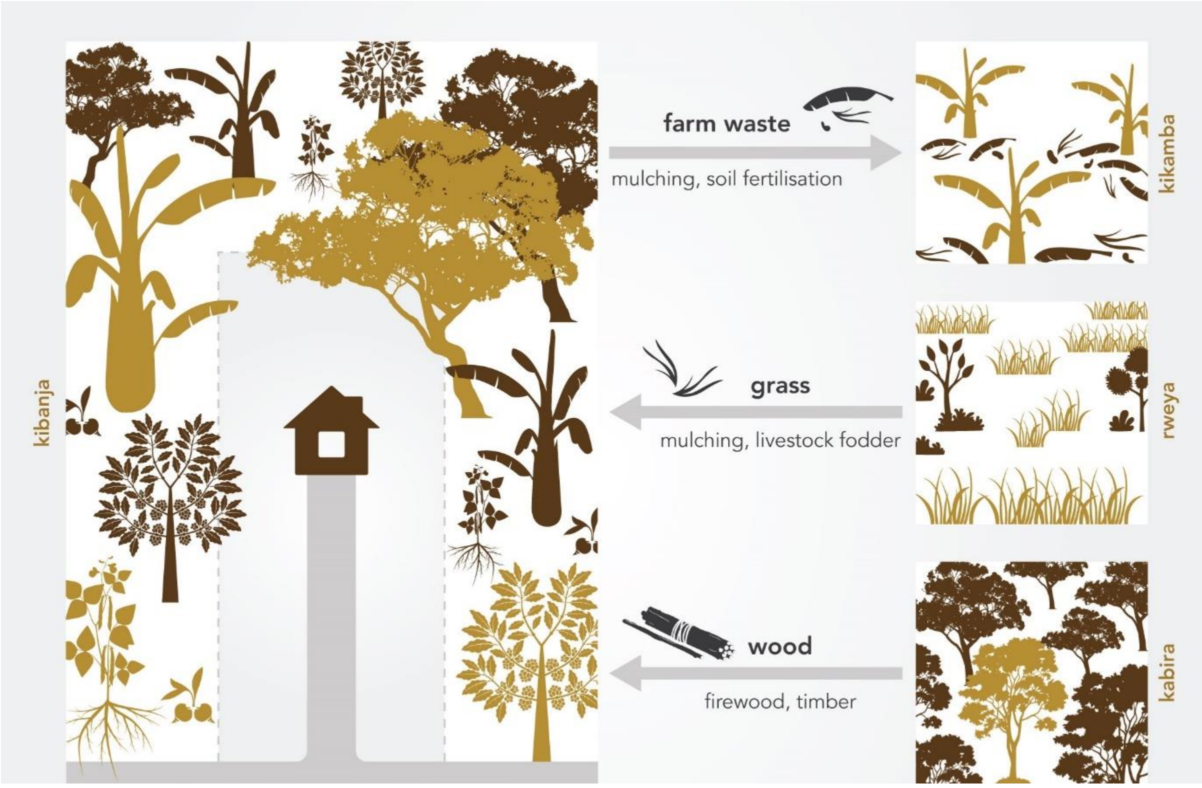


Fig. 1-12: Flows of significant organic farm waste, grass, and firewood between the four components of traditional banana-coffee-based farming systems. The older and younger homegardens are called kibanja and kikamba in the local Bantu language, the woodland is called kabira, and the grassland rweya. The figure is modified after Baijukya and Steenhuijsen Piters (1998) and Reetsch et al. (2020a).

Biomass and organic farm waste circulate between the four components. In this traditionally family-based farming systems, knowledge has been transferred from the older generations to the younger (Copeland Reining 1967). The people live mainly on the proceeds of their smallholder family farming activities and small businesses. The banana-coffee-based farming systems have been described in further detail in the background information of the journal article presented in chapter 2.2.1 and the book chapter presented in chapter 3.1.1.

Organic farm waste management

For a millennium, the banana- coffee-based farming systems were densely covered with vegetation (*cf.* Baijukya and Steenhuijsen Piters 1998; Copeland Reining 1967; Rugalema *et al.*, 1994). Then, the fertility of these agroforestry systems depended on the constant care of the crops and the excellently adapted use of organic farm waste, which was regarded less as waste than as an integral part of the system (*cf.* Baijukya and Steenhuijsen Piters 1998; Copeland Reining 1967; Touber and Kanani 1996). Farmers frequently collected crop residues, animal manure and kitchen waste throughout the year and spread them on the fields near the houses, in the so-called homegardens. In this way, the soil was always covered and protected from water and wind erosion, as well as being constantly fertilised with new organic material. The organic material was decomposed by the soil organisms and mineralised nutrients were made available to plant roots. Thus, composting and mulching of organic farm waste have played a crucial role in replenishing soil nutrients and organic matter, improving nutrient and water uptake by plants, and combating soil drying and erosion (Baijukya and Steenhuijsen Piters 1998; Copeland Reining 1967; Touber and Kanani 1996).

This traditional organic farm waste management has changed over the past 60 years (*cf.* Copeland Reining 1967; Henao and Baanante 2006; Krause and Rotter 2018; Touber and Kanani 1996). Traditional, current and modified organic farm waste management techniques are described in more detail in the journal article presented in chapter 2, the book chapter presented in chapter 3, and the journal article presented in chapter 4.

1.2.3 Social, economic, and ecological challenges

Kagera's population has faced and is still facing enormous social challenges. Among them are fast population growth, high age-dependency ratios, hunger, and the prevalence of HIV/AIDS and tropical diseases, e.g., malaria. In addition, the population has had to cope with a massive influx of refugees. Today, the study area is among the most impoverished regions worldwide, where people are exposed to high food insecurity (FAO 2015). About 95% of the population is engaged in agriculture and forestry and half of them keep livestock, mainly poultry, goats, cattle, and sheep (URT 2016). Food security is low in this region. Agricultural production per capita has declined since the late 1980s due to the consequences of population growth, the refugee inflow, and the impacts of the HIV virus spreading. Today, forest and farmland alike – in this originally densely covered, species-rich region – have been degraded (*cf.* Wasige et. al 2013). This covers both soil resources and vegetation cover. Agriculture has not adapted to climate change (FAO 2017). Soils are exposed to erosion by heavy rainfall and partly also by wind, and the use of fresh wood for firewood, and timber is increasing faster than trees regrow. Farming families have become impoverished due to poor yields, decreased farm size, limited non-agricultural sources of income, and diseases, i.e., malaria and AIDS (Lichtfield and McGregor 2008; Weerdt 2010). With the deaths of adult family members, the traditional sharing of agricultural knowledge with succeeding generations has been interrupted (*ibid.*).

Tanzania's population structure shows an unusual pattern, because regions close to the borders, like the Kagera region, are more densely populated than regions in the centre of the country (Young 2002). Karagwe's population grew from 29,000 inhabitants in 1918 to 99,500 inhabitants in 1967, and further to 653,046 inhabitants in 2012, with an average annual population growth of 2.4% between 1988 and 2012 and a population density of 477 people per km^2 of arable land in 2012 (Katoke 1970; URT 2012, 2016). In the same districts, almost half of the population are children under 14 years, and almost another half is of working age, defined here as between 15 and 64 years (URT 2016). The literacy rate increased between 2001 and 2012 from 67% to 79% in the Karagwe district, and from 66% to 92% in the Kyerwa district (*ibid.*). The average household size was five people; however, it was appreciably higher in female-headed rural households, which comprised an average of eight people (*ibid.*). Also in 2012, the age-dependency ratio in rural Kagera was very high (109.5), meaning that every 100 people of working age cared for 109.5 children under 14 or elderly people over 65. In comparison, the world's average age-dependency ratio was 54.1 in the same year; Tanzania as a nation ranked 15th in the world in this respect, with an age-dependency ratio of 93.8 (World Bank 2017). Since the majority of female-headed households belong to widowed, divorced, or unmarried women, they often have a higher age-dependency ratio, hold fewer assets including land and livestock, and are more exposed to poverty than male-headed households.

The outbreak of HIV and AIDS in the 1980s

In the 1980s, the HIV and AIDS epidemics afflicted the Kagera region. The first cases of HIV infections were documented there in 1983, after which they spread particularly fast in urban areas; e. g., one quarter of the population in Bukoba Urban District was HIV-positive in 1987, and 4.5% in the rural Karagwe district (Kwesigabo 2001). The infection rate had declined throughout the whole region by 1999, primarily due to the formation of new social groups who cared for affected families, effected changes in sexual behaviour, norms, values, and customs, and formed new trust and social capital (Frumence *et al.* 2010, 2014; Kwesigabo 2001). The epidemics seriously harmed small farming families in a variety of ways. Besides declining farm productivity, local aid workers and researchers also reported losses of labour for nursing and mourning, losses of assets, selling of labour to buy medicine, declining self-esteem in children who had lost a parent, along with an increase in dependencies, adult mortality, household instability, and orphan-headed households (Rugalema 1998; Tibaijuka 1997; Weerdt *et al.* 2017). Orphanhood enormously increased during the HIV and AIDS pandemic (Weerdt *et al.* 2017). Today, 7.2% of Tanzania's children are orphans (URT 2016). As one consequence, women marry earlier than men, at 20 years old on average, or up to three years earlier if they are orphans (Beegle and Krutikova 2008). In comparison, the average man marries for the first time when he turns 24, and the age at which a man enters into marriage only reduces after the loss of a non-parental adult female relative (Beegle and Krutikova 2008; URT 2016).

Refugee migration since the 1990s

Beyond that, in 1993 and 1994 more than half a million refugees fled from Burundi and Rwanda into the Kagera region to escape the genocide of the Tutsi people and the pursuit of moderate Hutu people (Alix-Garcia and Saah 2010; Baez 2007; Musoke 1997). First, the rapid and unexpected mass migration overstressed the hosting region and caused food prices to skyrocket, and competition for jobs became increasingly problematic (Maystadt and Verwimp 2009). Second, the increasing demand for food, water, and firewood resulted in overuse of land and water resources, deforestation, environmental degradation, overstrained institutions, and an increase in sexually transmitted diseases, infant mortality, and crime (Baez 2007; Hagai 2019; Jacobsen 2002). However, beside negative effects, positive effects were also found for the hosting population, e.g., the acquisition of valuable goods (Maystadt and Verwimp 2009). Farmers relying on subsistence agriculture were less affected by the negative effects of refugee migration than workers who relied on being employed by others, whether in agricultural or non-agricultural businesses (*ibid.*). In spite of their initial hospitality and some long-term positive effects, hostility grew against the refugees, and Rwandan refugees were forced by the Tanzanian military to settle back in Rwanda in 1995 (Musoke 1997). Due to successful political interactions between Tanzania and Burundi, Burundian refugees were permitted to stay (*ibid.*). Unti today, the population in the Kagera region constantly hosts refugees from neighbouring countries and the Congo.

1.3 Objectives

The main objective of this thesis is to investigate the extent to which organic farm waste is integrable into the biomass production of degraded smallholder banana-coffee-based farming systems in the study area, the Kagera region in north-west Tanzania. This overall objective can be subdivided into four targets. The first is to improve soil characteristics that are favourable for agricultural production. The second aims to increase food production to enhance food security for the local population. The third is to enhance the provision and generation of energy (>95% traditionally is biofuel). And the fourth focuses on the reduction to reduce poverty among the rural population. A further point of discussion is whether the traditional sources of energy, which are firewood and charcoal, are the most appropriate for this region nowadays. The overall goal is to secure sustainable food and biofuel production to the extent that the local population is not going hungry throughout the year, sufficient income is generated to meet at least their basic needs (e.g., medical requirements), children can attend school; in other words, to secure food supply and to combat poverty in the long term.

To achieve the main objective, i.e., the improvement of soil fertility, existing uses of organic farm waste are described and evaluated. Unused nutrients in organic farm waste are identified. It is also examined whether degraded banana-coffee-based farming systems can regain their former diversity and fertility through optimised farm waste management. Local initiatives have already attempted to counteract food insecurity and impoverishment. This research also addresses the successes achieved and lessons learnt by one local farmer field school. The thesis concludes by considering whether the optimised utilisation of organic farm waste as soil fertiliser and conditioner is sufficient to achieve food and energy security in the Kagera region.

In the broader context, this thesis seeks to contribute to the achievement of the following the Sustainable Development Goals (SDGs) of the United Nations (UN): Goal 2 (zero hunger), Goal 7 (affordable and clean energy), and Goal 15 (life on land). Therefore, targets and indicators of related SDGs and their entry points are discussed, as well as the internationally recognised Water-Energy-Food (WEF) Nexus and the adapted Water-Soil-Waste (WSW) Nexus. The United Nations University (UNU) has combined both Nexi into one concept: The Resource Nexus: *"UNU-FLORES is the go-to place for scientists and decision makers in search of a holistic resource nexus approach embracing water, soil, waste, energy and other geo-resources."* (Edeltraud Guenther 2019, Nexus Seminar No. 41 on Measuring and Managing the Resource Nexus). The Resource Nexus can be modified on a case-by-case basis and adapted to the measure concerned (*cf.* Hülsmann and Jampani 2021; Liu *et al.* 2018). Recommendations for action and policy development for the Tanzanian Ministry of Agriculture and the National Land Use Planning Commission (NLUPC) have been derived from the research results. These options for action in particular target at long-term soil fertility and sustainable agricultural intensification to strengthen food and energy security. Accordingly, optimised measures for sustainable, agricultural intensification have been derived and evaluated (*cf.* chapter 6). Conclusions can also be drawn for similar situations in other regions.

1.4 Research questions

Following the main objectives and its targets, three research questions are investigated and answered in this thesis. In the scope of the first research question, the *status quo* of organic farm waste management in the study area is analysed (chapter 1.4.1). In the second research question, modified farm waste management practices are studied and compared to the *status quo* (chapter 1.4.2). Based on this comparison, the nutrient balances (NBs) of nitrogen (N), phosphorus (P), and potassium (K) are analysed for the homegardens of the banana-coffee-based farming systems (*cf.* Fig. 1-12) to investigate whether nutrient cycles could be closed, and soil fertility and biomass production increased (chapter 1.4.3).

1.4.1 The status quo of organic farm waste management

The first research question investigates the *status quo* of organic farm waste management in degraded smallholder banana-coffee-based farming systems in the study area. The aim is to obtain a holistic picture of today's organic farm waste management in these farming systems. The research question has been divided into five sub-questions:

> How can the *status quo* of the organic farm waste management in degraded smallholder banana-coffee-based farming systems be described and categorised?
>
> a. *Categorisation*: How can farm households be grouped according to their agricultural production and socio-economic conditions?
> b. *Description*: How can current farm waste management practices be described?
> c. *Farm waste use*: How do farm households in each identified group use organic farm waste today?
> d. *Influence on yields*: How is current farm waste management affecting the yields of annual and perennial crops?
> e. *Modification*: Are farmers willing to use human excreta as a feedstock in composting in the future?

Farm waste management involves the collection and treatment of organic farm waste, and its use for plant nutrition and soil amendment. Nutrient management plays an important role in this. Organic farm waste includes residues from annual and perennial crops and trees, kitchen and food waste, and livestock manure, and in some cases human excreta. Residues from the cooking process over a fire are called 'cooking ash' and are also considered as farm waste in this thesis, although it is inorganic.

A recent development worldwide is that human excreta are being increasingly considered as organic farm waste in agriculture, which has previously seldom been the case due to concerns over hygienic (Moya *et al.* 2019; Okem and Odindo 2020). There have been repeated attempts in research worldwide to use human excreta as fertiliser, especially for the recovery of phosphorus (*cf.* Heinonen-Tanski and van Wijk-Sijbesma 2005; Mihelcic *et al.* 2011; Winker *et al.* 2009). Meanwhile, recommendations for the use of human urine in agriculture exists (*cf.* Andersson 2015), but there is barely any information on the risk-free use of human faeces. In particular, infection with helminth eggs, or bacteria such as *Salmonella* spp., *Shigella* spp., and *Yersinia* spp., cause a well-characterised spectrum of diseases in human bodies (Dekker and

Frank 2015). Besides, social acceptance of the use of human excreta-derived fertiliser might be limited (*cf.* Malila *et al.* 2019; Massoud *et al.* 2019).

To answer the first research question, I interviewed 150 smallholder households on the availability and uses of organic farm waste on their farmland at the beginning of the *Vuli* rainy season from September to November 2017. The survey encompasses geographical variables; household information; agricultural information related to water, soil, and farm waste (Water-Soil-Waste Nexus); economic data; and water, energy, and food availability (Water-Energy-Food Nexus). The methodology is described in more detail in chapter 2.3. The findings serve as a baseline for the second research question, in which the modification of traditional farm waste management has been investigated. The results have been published as a journal article in Reetsch *et al.* (2020a; chapter 2), a book chapter in Reetsch *et al*. (2020d; chapter 3) in which traditional composting techniques are compared to modified techniques in the Morogoro region in central Tanzania, and a data set and a data article in Reetsch *et al.* (2020c, 2021a; appendix from page 233 onwards).

1.4.2 The transition towards multifunctionality

The second research question investigates the modification of organic farm waste management practices in the study area. The aim is to compare experiences and techniques of advanced waste management with the *status quo*. The second research question asks:

> How could organic farm waste management be improved in degraded banana-coffee-based farming systems to increase soil fertility and biomass production?

To answer the second question, I analysed the achievements of the local farmer field school (FFS), MAVUNO Project, which has developed and applied training in sustainable land management (SLM) in the study area since the early 2000s. Farmers have sought to counteract the degradation of vegetation and soil resources, and to adapt to climate change in self-organised field schools. The FFS has established training in SLM in cooperation with diverse international organisations and research institutes to regain the multifunctionality of previously fertile homegardens of banana-coffee-based farming systems. The concept of multifunctionality in land-use builds the theoretical background of these research questions. Referring to the definition proposed by Zhang and Schwärzel (2017), multifunctionality includes *'diverse demands on agricultural land that are met by the production of several goods and services, either on one land-use type or several land-uses on one piece of land, assuming that each action has a function, and that ecosystem services are provided at the same time'*.

The overall goal of the training is to increase food and energy security and to diminish poverty under the current circumstances. Therefore, it includes measures connected to agroforestry, livestock-keeping and monitoring, integrated organic farm waste and soil fertility management, pesticide management, soil and water conservation, afforestation, agricultural accounting, marketing, communication, work allocation, time management, and gender-inclusive communication and decision-making. In addition, the FFS is about to implement the findings of a research team from Technische Universität Berlin that has developed 'CaSa-compost' (Carbonisation and Sanitation compost) by integrating biochar with sanitised human excreta, and has tested the application in a field trial on the FFS's farmland (Krause *et al.* 2015, 2016; Krause and Rotter 2017, 2018). The complete CaSa-compost methodology, its strengths and weaknesses are examined and discussed in the chapters 2, 4 and 5.

Accordingly, the second research question is divided into two sub-questions:

a) *Categorisation and differentiation*: How do trained farm households differ from each other and from untrained households in terms of (i) land size and agricultural production, (ii) farm waste management, (iii) economy, (iv) food security and drinking water, (v) climate change adaptation, (vi) gender-inclusive communication, (vii) education, and (viii) energy use?
b) *Transformation process*: Which improvements, challenges, and bottlenecks exist, what lessons have been learnt, and what further development is needed?

To answer the second research question, I organised five focus group discussions (FGDs) with the 22 trainers of the FFS. In the FGDs, the trainers first developed an expert-based farm household typology to find similarities and differences among the trained households. Then, they discussed the characteristics of each identified group of households and their agricultural production, including waste management. They were also asked whether they thought the implementation of CaSa-compost was promising or not. At the end, each trainer was individually interviewed. The results of this part are included in a submitted journal article Reetsch *et al.* (2021b; chapter 4) and have served as a basis for the third research question.

1.4.3 The optimisation of farm waste management

The third research question analyses and assesses the optimisation of existing farm waste management practices in the study area. The aim is to assess the potential of farm waste as an organic fertiliser and soil conditioner, and its optimal integration into degraded banana-coffee-based farming systems to improve soil fertility. This analysis is key to drawing conclusions for improving food and energy security in the studied region. The third research question is divided into two sub-questions:

> Can negative nutrient balances (NBs) in degraded banana-coffee-based farming systems be turned positive if organic farm waste management is optimised and well-integrated into the agricultural production cycle?
>
> a) *Inventory:* Are NBs in the homegardens of trained households more positive than in those of untrained households?
> b) *Potential:* Can nutrient cycles be closed through composting?

Both groups of smallholder farm households, the untrained and the trained one, are compared to each other regarding farm waste and nutrient management and its impact on their agricultural productivity. Therefore, I calculated NBs for nitrogen (N), phosphorus (P), and potassium (K) in the homegardens of both comparative groups.

This analysis is based on the principles of the circular economy (CE). Pearce and Turner (1989) determined the conceptual framework of the CE as *"the central theme of the CE concept is the valuation of materials within a closed-loop system with the aim to allow for natural resource use while reducing pollution or avoiding resource constraints and sustaining economic growth"* (Winans *et al.* 2017). These principles were already applied in nutrient analyses in the 1940s, 1960s, and 1970s (Dumenil 1961; Geraldson 1977; Tyner and Webb 1946). This approach is not new to smallholder farming families in East Africa who seek to use and reuse materials on their farms by tradition (*cf*. Copeland Reining 1967). Using organic farm waste as fertiliser is still the most prominent example of the applied CE in East African agriculture. Another example of the reuse of waste in agriculture is the use of old plastic water bottles for drip irrigation.

The methodology behind this analysis is the material flow analysis (MFA) according to Baccini and Brunner (2012). An MFA is similar to a life cycle assessment within a specific environment. Both authors also take human factors and the resulting social and economic aspects into account. In their book 'The Metabolism of the Anthroposphere', they describe the anthroposphere as a *global network of human systems, which in turn, as complex, technical systems, absorb, transport, store, chemically transform and release substances, energies and/or information in altered quality and quantity. In human systems, resources are needed for human existence, i.e., used, transformed, and passed on by humans, either back to nature or to another human system." (Baccini and Brunner, 2012).* In this context, Baccini and Brunner (2012) assume that social transformations are characterised and accompanied by changes in the flow and storage of materials. This assumption can be applied to the comprehensive transformations that occurred in Africa in the 21st century, i.e., economically (Gray 2018; Wuyts and Kilama 2014) including agriculture (FAO 2017), and politically and socially (Dutt and Grabe 2017; Louis and Montiel 2018), which are now leading to a re-sorting of material flows.

In this thesis, the following hypothesis is deduced: "Organic waste flows in the agricultural sector of the study area are no longer integrated to a high degree due to complex social challenges (*cf*. chapter 1.2.3), which makes the new (re)integration of organic waste flows necessary if food and energy security is to be achieved once more among the local population". Taking the hypothesis into consideration, the second research question is further sub-divided into:

c) *Scenarios:* In which scenarios could NBs be optimised?
d) *Beneficial conditions:* What other ecological and socio-economic conditions need to be met in order to close nutrient cycles at the farm level?

To prove or disprove this hypothesis, I have developed four scenarios based on the scheme of biomass and waste flows and stocks in the homegardens of banana-coffee-based farming systems (Fig. 1-13). The scenarios consider either the sanitised integration of human urine or the CaSa-compost as fertilisers, the promotion of legumes, and finally a combination of the three. The results of this part have been published as a journal article in Reetsch *et al.* (2020b; chapter 5).

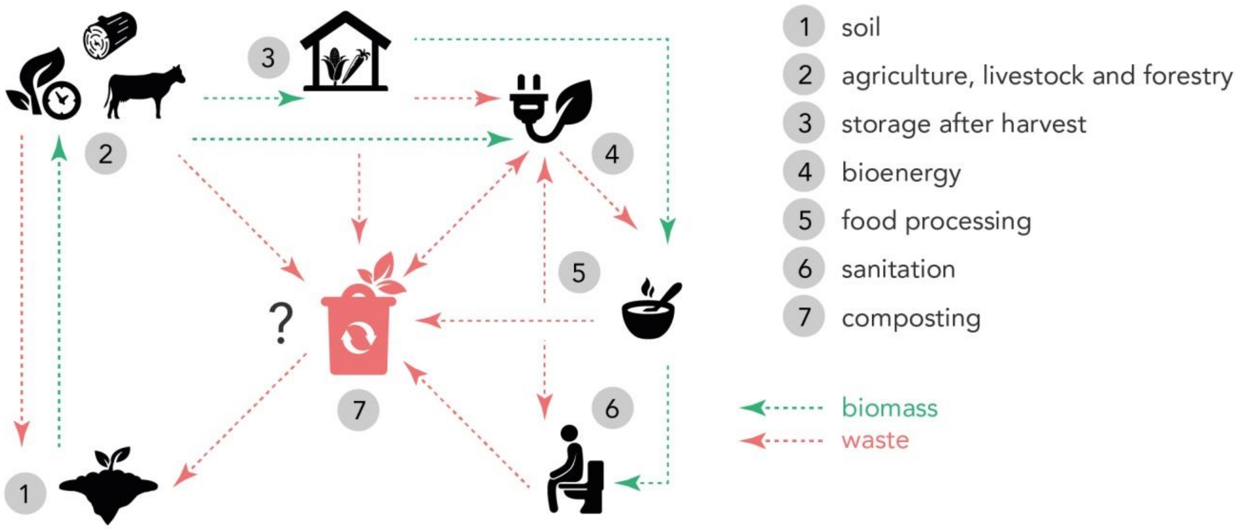


Fig. 1-13: Scheme of the circular economy in a banana-coffee-based farming system. In the seven elements shown, biomass is produced (green arrows), consumed, and waste generated (red arrows). The graphic is modified after Baccini and Brunner (2012) and Krause et al. (2015).

1.5 List of publications

This list of publications includes three journal articles (two published and one submitted), one data article, one data set, two book chapters, and six conference proceedings.

Chandrasekhar, P., **Reetsch, A.**, Patra, S., Ardakanian, R., and Schwärzel, K. **2018b**. "Advancing the Soil-Water-Waste Nexus Approach for Achieving the Sustainable Development Goals." In *Soil and Sustainable Development Goals*, edited by Lal, R. Horn, R. and Kosaki, T., 126–38. Stuttgart, Germany: Schweizerbart. https://www.iuss.org/publications/soil-publications/soil-and-sustainable-development-goals/.

Reetsch, A., Feger, K.-H., Schwärzel, K., Dornack, C., and Kapp, G. **2020a**. "Organic Farm Waste Management in Degraded Banana-Coffee-Based Farming Systems in NW Tanzania." *Agric. Syst.*, 185, 102915, https://doi.org/10.1016/j.agsy.2020.102915.

Reetsch, A., Schwärzel, K., Dornack, C., Stephene, S., and Feger, K.-H. **2020b**. "Optimising Nutrient Cycles to Improve Food Security in Smallholder Farming Families—A Case Study from Banana-Coffee-Based Farming in the Kagera Region, NW Tanzania." *Sustainability* 12, 9105, https://doi.org/10.3390/su12219105.

Reetsch, A., Schwärzel, K., Kapp, G., Dornack, C., Masisi, J., Alichard, L., Robert, H., Byamungu, G., Stephene, S., and Feger, K.-H. **2020c**. "Survey of 150 Smallholder Farm Households in Banana-Coffee-Based Farming Systems Containing Data on Farm Households, Agricultural Production and Use of Farm Waste." *Pangaea*, https://doi.pangaea.de/10.1594/PANGAEA.914713.

Reetsch, A., Kimaro, D., Feger, K.-H., and Schwärzel, K. **2020d**. "Traditional and Adapted Composting Practices Applied in Smallholder Banana-Coffee-Based Farming Systems: Case Studies from Kagera and Morogoro Regions, Tanzania." In *Organic Waste Composting Through Nexus Thinking: Practices, Policies*, edited by Hettiarachchi, H., Caucci, S., and Schwärzel, K., 165–84. Cham, Switzerland: Springer Nature. https://doi.org/10.1007/978-3-030-36283-6_8.

Reetsch, A., Schwärzel, K., Kapp, G., Dornack, C., Masisi, J., Alichard, L., Robert, H., Byamungu, G., Rocha, J. L., Stephene, S., Frederick, B., and Feger, K.-H. **2021a**. "Data Set of Smallholder Farm Households in Banana-Coffee-Based Farming Systems Containing Data on Farm Households, Agricultural Production and Use of Organic Farm Waste." *Data Brief*, 35, 106833, https://doi.org/10.1016/j.dib.2021.106833.

Reetsch, A., Feger, K.-H., Schwärzel, K., and Kapp, G. **2021b**. "Transformation of degraded banana-coffee-based farming systems into multifunctional agroforestry systems – A mixed methods study from NW Tanzania." *Agri. Syst. (under review).*

Conferences

Reetsch, A., Feger, K.-H., Schwärzel, K., Dornack, C., and Kapp, G. **2016**. "Der Einbindung Organischer Abfälle in die Biomasseproduktion Multifunktionaler, Kleinbäuerlicher Farmsysteme Ostafrikas." *Proceedings DGAW e. V.*, 6. Wissenschaftskongress „Abfall- und Ressourcenwirtschaft", Berlin, Germany, 10 to 11 March 2016, https://www.dgaw.de/veranstaltung/wissenschaftskongress/wiko-2016.

Reetsch, A., Feger, K.-H., Schwärzel, K., Dornack, C., and Kapp, G. **2018**. "Integration of Organic Waste into the Biomass Production of Smallholder Farming Systems in the Kagera Region, NW-Tanzania." *Proceedings DGAW e. V.*, 8. Wissenschaftskongress „Abfall- und Ressourcenwirtschaft", Vienna, Austria, 15 to 18 March 2018, https://www.dgaw.de/veranstaltung/wissenschaftskongress/wiko-2019-1.

Reetsch, A., Feger, K.-H., Schwärzel, K., Dornack, C., and Kapp, G. **2019a**. "The Integration of Organic Farm Waste in Degraded Smallholder Banana-Coffee-Based Farming Systems in the Kagera Region, Tanzania." In *Filling Gaps and Removing Traps for Sustainable Resources Management: Book of Abstracts*, 124–125. Tropentag, Göttingen, Germany, 18 to 20 September 2019. Göttingen, Germany: Cuvillier Verlag. https://www.tropentag.de/2019/abstracts/abstracts.php?showtime=0&noID=1&menu=11.

Reetsch, A., Kapp, G., Feger, K.-H., Schwärzel, K., and Dornack, C. **2019b**. "Transforming Degraded Smallholder Farmland into Multi-functional Land Use Systems: A Case Study from Tanzania." *Proceedings of Terra en Visión 2019*, Terra en Visión, Barcelona, Spain, 2 to 7 September 2019, https://terraenvision.eu/2019-abstracts/.

Reetsch, A., Feger, K.-H., Schwärzel, K., Dornack, C., and Kapp, G. **2020a**. "Circular Economy in Smallholder Agriculture: Advancing Nutrient Cycling in Tanzania." *Proceedings DGAW e. V.*, 10. Wissenschaftskongress „Abfall- und Ressourcenwirtschaft", Dresden, Germany, 8 to 9 October 2020, https://www.dgaw.de/veranstaltung/wissenschaftskongress/wiko-2020.

Reetsch, A., **2020b**. "Rediscovered Tradition: Composting as a Central Part in the Circular Economy in Smallholder Agriculture in East Africa." Dresden Nexus Conference, Dresden, Germany, 3 to 5 June 2020, https://2020.dresden-nexus-conference.org.

2 *Status quo* of organic farm waste management

This chapter has been published as a journal article, data article, and a data set. The journal article is presented in this chapter. The data article and the data set are presented in the appendix from page 233 onwards.

Reetsch, A., Feger, K.-H., Schwärzel, K., Dornack, C., and Kapp, G. **2020a**. "Organic Farm Waste Management in Degraded Banana-Coffee-Based Farming Systems in NW Tanzania." *Agric. Syst.*, 185, 102915, https://doi.org/10.1016/j.agsy.2020.102915.

Agricultural Systems 185 (2020) 102915

Organic farm waste management in degraded banana-coffee-based farming systems in NW Tanzania

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https://doi.org/10.1016/j.agsy.2020.102915

Received 20 August 2019; Received in revised form 23 July 2020; Accepted 27 July 2020

0308-521X/

Highlights

- Smallholder farm households that apply organic farm waste to their fields have higher yields.
- Female-led households remain the most vulnerable to food security.
- The potential of organic farm waste in sustaining soil fertility has not been fully realised.
- Knowledge of organic farm waste management has decreased since the outbreak of HIV/AIDS.

Graphical abstract

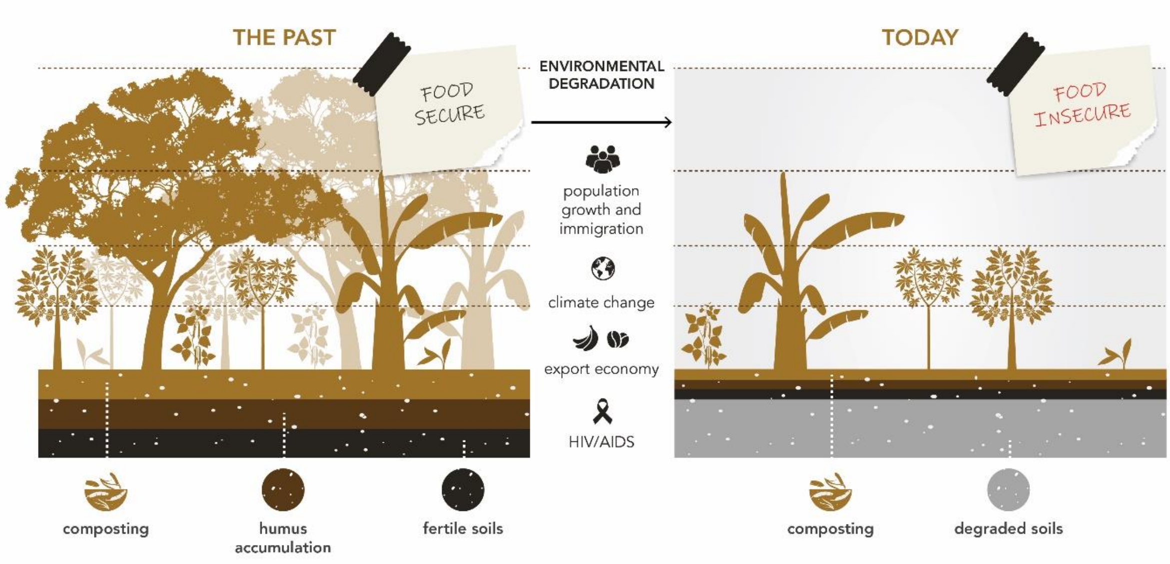

Fig. 2-1: Degradation of smallholder banana-coffee-based farming systems in the Kagera region of Tanzania. Banana-coffee-based farming systems have developed over the past millennium, and fertile farming systems ensured the food supply of the local population until the 1960s. Since then, however, soil resources and vegetation have been degraded, jeopardising food security for today's smallholders. Composting has become of secondary importance for maintaining soil fertility. (Design: Claudia Matthias).

Abstract

This study examines how smallholder farmers operate degraded banana-coffee-based farming systems and apply organic farm waste. We surveyed 150 farm households in two districts of the Kagera region in north-west Tanzania (Karagwe and Kyerwa districts). An expert-based typology revealed three groups of farm households that differ in biomass production (high, moderate, low). Households producing high amounts of biomass have integrated a sophisticated farm waste management system, but do not exploit the full potential of organic farm waste as a soil fertiliser and conditioner. The integration of farm waste management decreases in farm households with medium and low biomass production. None of the households is food secure, as they experience seasonality in food production and lack food storage technologies. In farm households with high and medium biomass production, the optimised use of organic farm waste could potentially lead to food security if food storage capacities were also improved. However, farm households with low biomass production will not become food secure with the introduction of organic farm waste management alone, as the land size is too small, and the socio-economic basis for it is lacking. Limited labour remains a major restriction to improving farm waste management. In the future, the safe use of human excreta needs to be fostered in engineering and research, holistic material flow analyses integrating (low-tech) agricultural solutions and concepts investigated, e.g., biochar production, safe use

of mineral fertiliser and climate-smart agriculture, and the socio-economic status of female-headed households strengthened, e.g., in farmer field schools and governmental programmes.

Keywords

Smallholder agriculture; farm waste management; composting; soil fertility; food security; gender

2.1 Introduction

In East African agricultural economies, smallholder farming accounts for more than two-thirds of agricultural production and employment (Salami *et al.* 2010). Soil nutrient balances in smallholder agriculture are usually positive in well-managed, biologically diverse homegardens near the farmhouse, but often become negative with increasing distance from the farmhouse and poor management (Stoorvogel and Smaling 1990; Stoorvogel *et al.* 1993; Baijukya and de Steenhuijsen Piters 1998; Vanlauwe and Giller 2006). Besides, soil nutrient balances at farm level can be very different to those at regional or national level, and depend on soil properties as well as nutrient inflows and outflows. For example, measurements have been reported of between −13 and −208 N kg ha^{-1} $year^{-1}$ at farm scale (Kiboi *et al.* 2019) and −28 and −39 N kg ha^{-1} $year^{-1}$ at national scale in East African countries (Henao and Baanante 2006). As a result, insufficient or no fertilisation of depleted soils endangers crop production, and with it the food security of entire smallholder families and the local non-agricultural population, as well as reducing crop exports (Smaling and Braun 2008; Mkonda and He 2018). As a further consequence, low crop yields diminish the prosperity of smallholder families, and poverty-affected farmers produce lower yields (Tittonell and Giller 2013; Franke *et al.* 2019). Although soil nutrient deficiency is not the only reason for low crop yields, farm nutrient management is essential in order to maintain soil fertility and food production, and ensure the continuance of ecosystem services, divided into provisioning (food, fodder, fibre, timber), regulating (prevention of erosion, water purification), supporting (nutrient cycling), and cultural (knowledge system and educational values) (Bekunda *et al.* 2005; Adhikari and Hartemink 2016).

This study examines the current role of composting in maintaining soil fertility in banana-coffee-based farming systems and the *status quo* of how smallholder farmers use organic farm waste in the Kagera region (Karagwe and Kyerwa districts) in north-west Tanzania. This paper aims at identifying the potential impact of farm waste management on biomass production in individual farm households and the differences between current and traditional uses of organic waste. The study area is known to be an important growing area for the East African Highland Banana (EAHB-AAA), other banana cultivars (*Musa* L. spp.), and coffee (*Coffea canephora* L. var. *robusta*). This hilly region is characterised by sub-humid climate conditions in which banana-coffee-based farming systems with integrated livestock husbandry have developed over the last millennium (Copeland Reining 1967; Katoke 1970; Schoenbrun 1993; Touber and Kanani 1996). Composting and mulching have played a crucial role in these mixed husbandry systems in replenishing soil nutrients and organic matter, improving nutrient and water uptake by plants, and combating soil drying and erosion (Copeland Reining 1967; Baijukya and Steenhuijsen Piters 1998; Lekasi *et al.* 1999; McIntyre *et al.* 2000). As a result, soils in the study area were fertile until the early 1990s, with an A-horizon several tens of centimetres thick and rich in humus, especially at the tops and feet of the hills (Milne 1936; Copeland Reining 1967; Touber and Kanani 1996).

Since the 1990s, the increasing demand for food and firewood from a continually growing local and refugee hosting population has led to severe environmental degradation in the form of deforestation, diminishing vegetation cover and density on farmland, increasing soil erosion, continual overuse of farmland and omission of fallow periods, soil nutrient mining, depletion and pollution of water resources and water storage capacity in soils, and reduced agricultural production in HIV/AIDS-affected households (Bekunda *et al.* 2005; Henao and Baanante 2006; Berry 2008; Wasige *et al.* 2013; Ruiz and Vargas-Silva 2018). The entire region is affected by environmental degradation. In particular, soils on slopes and hilltops are barely covered with vegetation, even after the beginning of the rainy season. More recently, soil degradation has been accelerated by climate change, which in the future may be aggravated by the projected changes in precipitation patterns and reductions in rainfall (FAO 2017; Gebrechorkos *et al.* 2018; Muthoni *et al.* 2018).

Previous research focussed on the outbreak of HIV/AIDS and the influence of refugee migration, and often concentrated on the coastal areas of the Kagera region, Bukoba and Bukoba Urban (e.g., Baijukya and de Steenhuijsen Piters 1998; Frumence *et al.* 2014). Compared to Bukoba, the remote Karagwe and Kyerwa districts have a different geochemical and geomorphological setting, climatic conditions, and history (see chapters 2.2.1 and 2.3.1). Few research activities in the Karagwe and Kyerwa districts have been carried out on soil degradation, soil fertility management and food security. Best-practice examples are the Transboundary Agro-ecosystem Management Project for the Kagera River Basin (Kagera TAMP), led by the Food and Agricultural Organization of the United Nations (FAO, 2017), and the Carbonisation and Sanitation (CaSa) project, in which experiments were carried out by a research team from Technische Universität Berlin and the Farmer Field School MAVUNO Project to further integrate human faeces and urine into soil fertility management (Krause *et al.* 2015, 2016; Krause and Rotter 2017, 2018).

We interviewed experts from non-profit and governmental organisations and surveyed 150 smallholder farm households. Based on the qualitative and quantitative data collected, we developed an expert-based farm household typology to identify commonalities and differences between the households surveyed using the following four research questions: 1) How can the farm households be grouped according to their agricultural production and socio-economic conditions? 2) How do farm households in each identified group use organic farm waste today? 3) How is their current farm waste management affecting the yields of each group of households? 4) Are farmers willing to use human excreta as a soil fertiliser?

Before presenting our analytical approach, we describe the development of the banana-coffee-based farming system and the traditional use of organic waste in the background chapter (chapter 2.2). Since the highest amounts and diversity of organic farm waste and most agricultural activities occur in the homegardens of the banana-coffee-based farming system, we concentrate our analysis on these. In the analysis, we assess gender-sensitive household data, yields of major food and cash crops, fruits and trees, livestock husbandry, and organic farm waste management. Finally, we compare the current use of organic farm waste with traditional use, and draw conclusions and recommendations to increase yields and soil fertility and thus improve long-term food security in smallholder agriculture.

As an overall goal, our research intends: 1) to deepen understanding of organic farm waste management in smallholder farming systems, 2) to identify current challenges, 3) to serve as a knowledge base for sustainable agricultural intensification in East African smallholder agriculture, and 4) to contribute to the achievement of the United Nations Sustainable Development Goals (SDGs) 'SDG 2: Zero hunger' and 'SDG 15: Life on land'.

2.2 Background

2.2.1 The development of banana-coffee-based farming systems in Karagwe

The first settlement of hunter-gatherers in Karagwe dates back 500,000 years, the first evidence of agricultural settlement by Bantu-speaking farmers 1000 years, and linguistic evidence on the cultivation of banana and cattle 500 to 1200 years (Katoke 1970; Schoenbrun 1993). In the 14th century, the Bantu-speaking Banyamboo formed patriarchal and exogamous clans, villages and communities, gradually expanding to form the Karagwe kingdom (Katoke 1970). These farmers cultivated sorghum, eleusine, millet, and yams as staple crops and were able to make pottery and iron farming tools (Katoke 1970). At the end of the 15th century, Bachwezi and Bahima people (from the territory known today as Ethiopia) conquered Karagwe, and the pastoralist Bahima, who settled on the plains, mixed with arable farmers from the Bantu Banyamboo, who preferred to stay among the hills (Katoke 1970). Mixed farming and a flowering trade and barter system developed in which banana seeds (*entembe* in the local language) were used as currency, and coastal goods, e.g., copper, salt, knives, peppercorns, mangoes, and oranges, were introduced to the region (Katoke 1970).

From the late 1830s, Arab and Kiswahili traders influenced the kingdom's economy and introduced cowries (*ensimbi*) as the new currency, along with coffee, sweet bananas, maize, pawpaw, vegetables, and citrus fruits as crops (Katoke 1970). The first Europeans entered Karagwe in 1860, and as the 19th century neared its close, internal conflicts between the native ruling clans, resultant wars, and epidemics, e.g., rinderpest and smallpox, led to the fall of the Karagwe kingdom, and to colonisation by Germany in 1885 and Great Britain in 1918 (Young 2002; Bjerk 2010). After decolonisation, Julius Nyerere became president in 1961, and as the founder of African socialism in Tanzania (*Ujaama*), he implemented villagisation of rural areas (*Vijiji*) between 1971 and 1975 (Bjerk 2010; Young 2002). By then, fertile banana-coffee-based farming systems had developed in highland perennial farming systems at altitudes over 1000 m above sea level (asl) (Garrity *et al.* 2012; Mwijage *et al.* 2016; Ruben *et al.* 2018).

Traditionally, a banana-coffee-based farming system consists of four land-use types appearing as an infinite mosaic of tiny, diverse land parcels: homegardens (in the local Bantu language called *kibanja*) surrounding the farmhouse, new farmland (*kikamba*), grassland (*rweya*) woodland (*kabira*); (Fig. 2-2; Copeland Reining 1967; Ndege *et al.* 1995; Baijukya and de Steenhuijsen Piters 1998; Baijukya 2004; Rugalema and Mathieson 2009). In polygynous families, the women usually live in separate farmhouses in close proximity to each other. In productive banana-coffee-based farming systems, the homegardens are characterised by a densely grown, multi-layered vegetation structure comprising annual and perennial crops, herbs, grass, medicinal plants, fodder plants, shrubs, fruit trees, and trees for firewood and timber production (Fig. 2-3; Reetsch *et al.* 2020). Smaller-growing annual crops, e.g., beans (*Phaseolus vulgaris* L. and other spp.), sweet potato (*Ipomoea batatas* L.), amaranth (*Amaranthus* spp.), and medicinal and fodder plants grow in the above-ground layer (Baijukya 2004). The second layer is dominated by coffee (*Coffea canephora* L. var. *robusta*), banana seedlings (*Musa* spp.), and lower-growing annual crops, e.g., cassava (*Manihot esculenta* Crantz and other spp.), maize (*Zea mays* L.), and sugarcane (*Saccharum officinarum* L.) (Rugalema *et al.*, 1994). Shading the underlying crops at 2.5 m to 5 m in height, adult banana plants and several fruit species dominate, e.g., avocado (*Persea americana* L.), mango (*Mangifera indica* L.), pawpaw (*Carica papaya* L.), guava (*Psidium guajava* L.), passion fruit (*Passiflora edulis* Sims), and tangerine (*Citrus* L. spp.) (Rugalema *et al.* 1994).

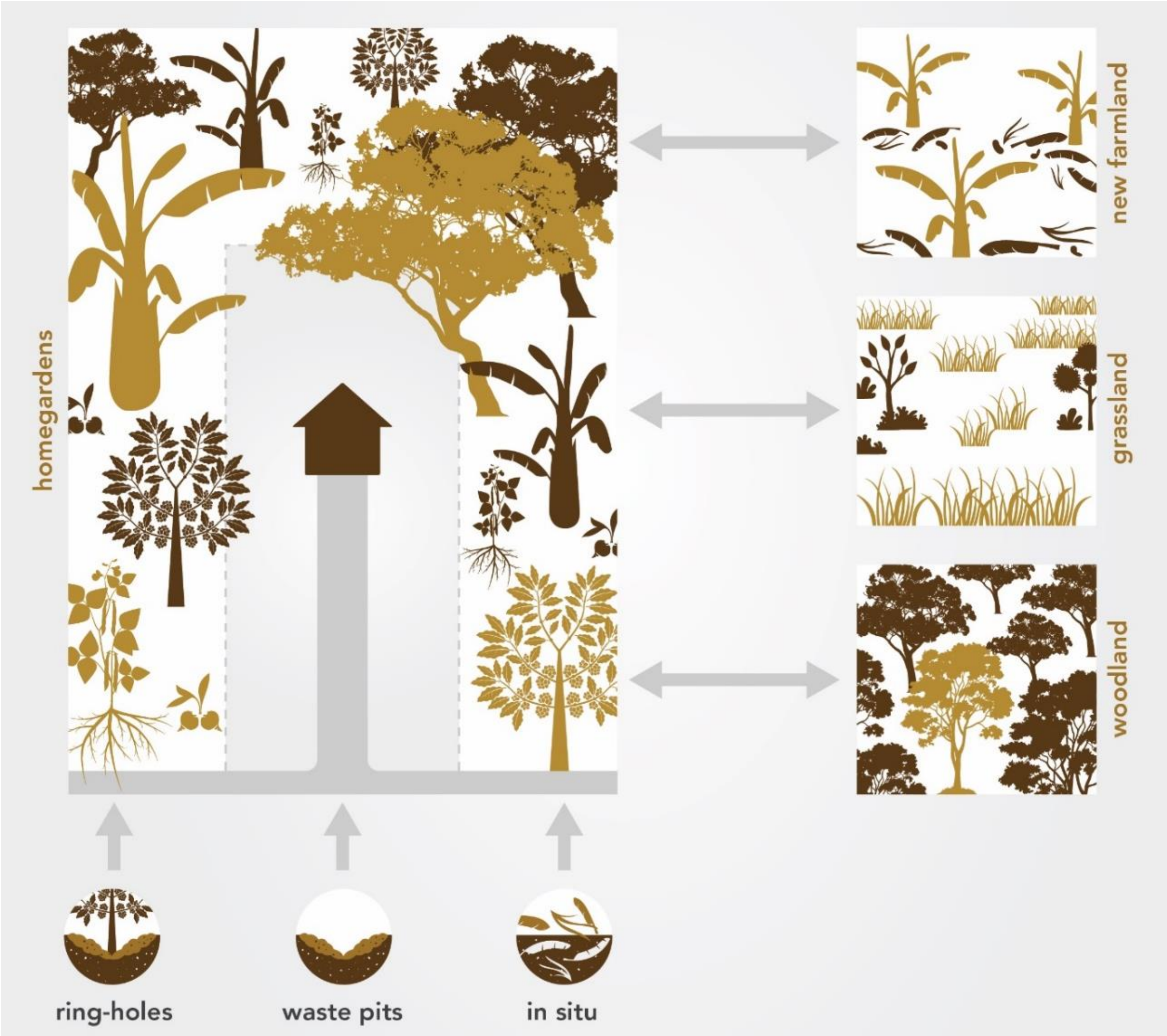

Fig. 2-2: Illustration of the land-use types in banana-coffee-based farming systems, modified from Reetsch et al. 2020. The main farming activities take place in the homegarden, where the farmhouse is located in the centre and a path leads to the road. At varying distances from the homegarden are new farmland, grassland, and woodland. (Design: Claudia Matthias).

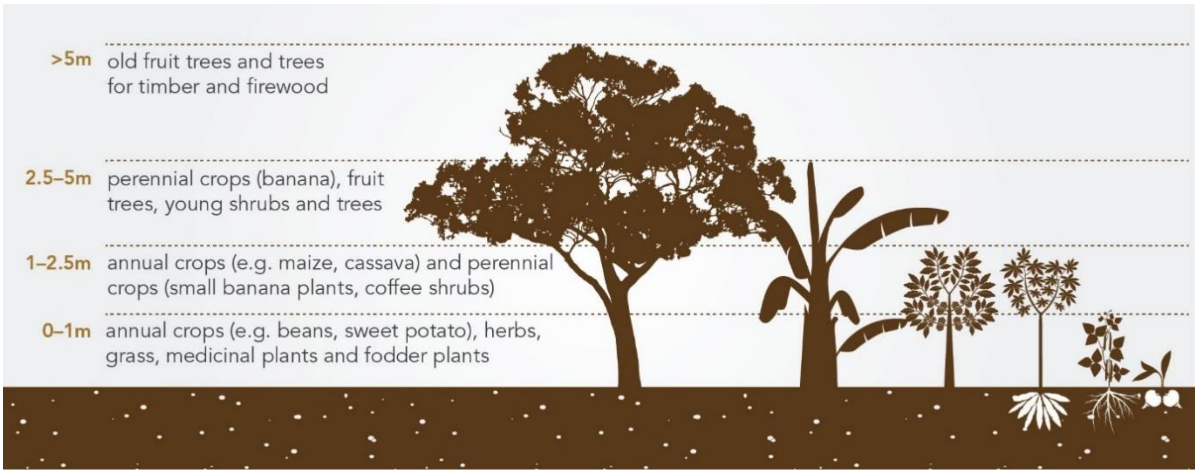

Fig. 2-3: Diagram of the multi-layered vegetation structure in the homegardens of productive banana-coffee-based farming systems; modified from Reetsch et al. (2020). (Design: Claudia Matthias).

In the highest vegetation layer, individual old fruit trees and trees for timber and firewood production are common, e.g., umbrella tree (*Maesopsis eminii*, known as *Omuhumula* in the local Bantu language), ficus (*Ficus* spp.: in Bantu *Omutoma*), silver oak (*Grevillea robusta*), and sand olive (*Dodonaea angustifolia*: in Bantu *Musambya*) (Rugalema *et al.* 1994; Baijukya *et al.* 2005).

Moreover, in 1993 and 1994 more than half a million refugees fled from Burundi and Rwanda into the Kagera region, and the sudden mass migration caused food prices to skyrocket and competition for work between labourers to increase, and also resulted in overuse of land and water resources, deforestation, environmental degradation, and overstrained institutions, as well as an increase in sexually transmitted diseases, infant mortality, and crime (Musoke 1997; Jacobsen 2002; Baez 2007; Berry 2008; Alix-Garcia and Saah 2010; Maystadt and Verwimp 2014).

To date, the majority of farmers in the region are still smallholders, and agriculture is the primary source of income alongside some smaller businesses, e.g., tailoring. However, smallholder farmers no longer produce only for themselves in subsistence agriculture. In recent decades, the relationship between subsistence farming and exports has shifted towards exports. Today, 39% of the total banana harvest in Tanzania is produced in the Kagera region, and 55% of the coffee (URT 2012, 2016).

2.2.2 The traditional role of organic farm waste

Organic farm waste includes crop and tree residues, kitchen and food waste, livestock manure and urine, cooking ash, animal bones, and human faeces and urine. According to findings by Copeland Reining (1967), plant-based farm waste was traditionally used as mulch, soil fertiliser, livestock feed, and for border markings in the homegardens or new farmland in banana-coffee-based farming systems. Leaves from banana plants and fruit trees, crop residues, and grasses were used as mulch (Copeland Reining 1967) – what we call *in situ* composting in this paper because it fulfils the purpose of soil fertilisation (Fig. 2-4 A, Reetsch *et al.* 2020). Besides, *in situ* composting has a mulching effect, prevents soil drying, reduces the risk of soil erosion, and enhances water infiltration, as long as bare soils are entirely covered with organic material. Before banana leaves were used as mulch, they would often have been used for several other purposes, like wrapping food or other transport goods and as plates for serving food (Copeland Reining 1967).

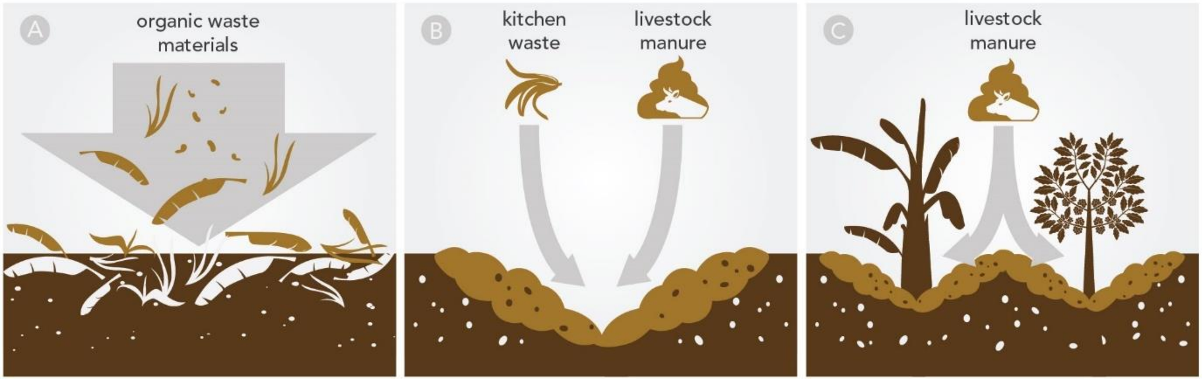

Fig. 2-4: Traditional composting techniques applied by smallholder farmers in banana-coffee-based farming systems in the Kagera region, Tanzania. Diagram A. illustrates in situ composting, B. pit composting, and C. ring-hole composting; modified from Reetsch et al. (2020). (Design: Claudia Matthias).

Kitchen waste was collected in waste pits near the houses and covered with grasses, crop residues, or earth (Copeland Reining 1967) in a process known as pit composting (Fig. 2-4 B, Reetsch *et al.* 2020). Most waste pits were established in close proximity to the farmhouses and were not opened again. Collected livestock manure was distributed in shallow holes around the perennial banana and coffee plants, and covered with earth to fertilise the surrounding soil (Copeland Reining 1967) – a technique known as ring-hole composting (Fig. 2-4 C, Reetsch *et al.* 2020).

As most of these composting techniques were employed close to the farmhouses, and more of the plants were also grown nearer the home, soil nutrient contents tended to be higher near the farmhouse, with a decreasing gradient towards the border of the homegarden (Copeland Reining 1967; Touber and Kanani 1996; Baijukya and de Steenhuijsen Piters 1998). The soils in the homegardens were rich in plant-available nutrients and characterised by deep, dark-coloured, humus-rich top-soils, although most subsoils developed on nutrient-poor bedrocks (Ndege *et al.* 1995; Touber and Kanani 1996; Baijukya and de Steenhuijsen Piters 1998).

2.3 Materials and methods

2.3.1 Study area

The study area is located at 1.0° to 2.1° S and 30.4° to 31.4° E in the Kagera region in NW Tanzania and covers seven wards of the Karagwe district (Kayanga, Nyakahanga, and Ndama wards in the Bugene division; Kituntu, Chanika, and Kihanga wards in the Kituntu division; and Nyaishozi ward in the Nyaishozi division), and six wards of the Kyerwa district (Isingiro ward in the Kaisho division; Kamuli, Kikukuru, and Kimuli wards in the Mabira division; and Nkwenda and Rukuraijo wards in the Nkwenda division; Fig. 2-5).

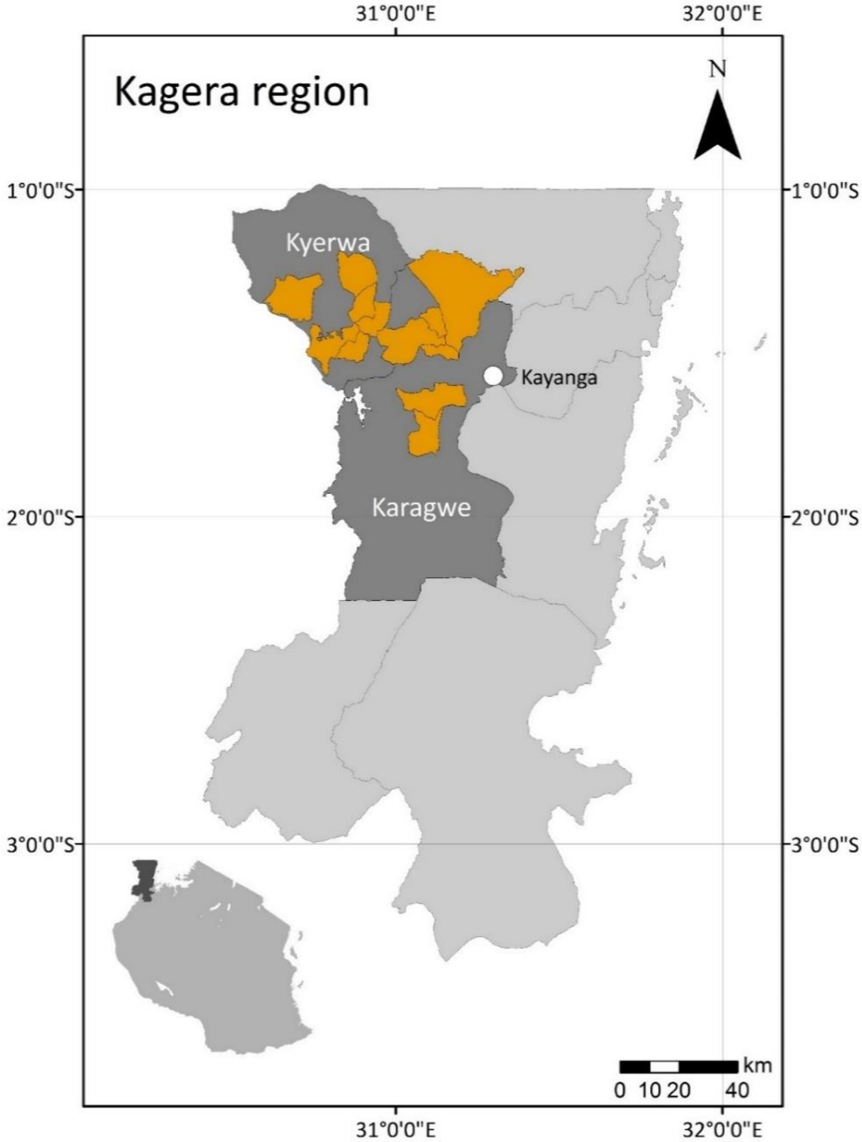

Fig. 2-5: Map of the study area, Kagera region in NW Tanzania (shape-files used from Map Library (2007)).

In this hilly terrain, altitudes vary between 1200 and 1650 m asl, and the study region is characterised by a bimodal rain pattern with an annual rainfall between 716 and 1286 mm (on average 982 mm ± 127 mm), and moderate temperatures, with minimum mean temperatures between 11.6 °C and 16.2 °C and maximum between 24.6 °C and 28.3 °C (Fig. 2-6; Touber and Kanani 1996; TMA 2017). The rain falls during the Masika rainy season from March to May and the Vuli rainy season from October to December.

Soil types vary on a small scale. Soils on slopes are often gravelly, shallow, and prone to erosion; soils on hilltops or ridges are suitable for agriculture if they are deep enough and not too gravelly, being dominated by sandy loam and clay loam textures, moderately deep, well-drained, and reddish-brown to brown; soils at the foot of slopes or in the valleys are the most suitable for agriculture due to their depth and high water storage capacity (Ndege *et al.* 1995; Touber and Kanani 1996). According to the World Reference Base of Soil Resources (FAO 2006a), soils in this region can be variously classified as *Ferralsols*, *Leptosols*, *Acrisols*, *Cambisols*, and *Phaeozems*; in river terraces as *Fluvisols*, *Gleysols*, and *Planosols*; in swamps as *Histosols* (Touber and Kanani 1996); and more recently as *Andosols* according to Krause *et al.* (2016).

The population in Karagwe and Kyerwa district has grown from 29,000 inhabitants in 1918 to 653,046 in 2012, with an average annual population growth of 2.4% between 1988 and 2012 and a population density of 477 people per km^2 of arable land in 2012 (Katoke 1970; Wasige *et al.* 2013; URT 2016). Today, the study area is among the most impoverished regions worldwide, where people are exposed to high food insecurity (Lichtfield and McGregor 2008; FAO 2015).

2.3.2 Methods

Data collection

In 2017, we interviewed eight agricultural experts who were familiar with the area, the farmers, and political decision-making processes. The experts were from two local non-profit organisations, i.e., WOMEDA (Women and Men for Destined Achievements, facebook.com/Womeda-285166848171570/) and the MAVUNO Project (mavunoproject.or.tz), as well as from the International Institute of Tropical Agriculture (IITA, iita.org/iita-countries/tanzania/), and the National Land Use Planning Commission (NLUPC, nlupc.go.tz). From the expert interviews, we identified the key wards and villages, in which we later surveyed 150 smallholder farm households out of a pool of 5000 farm households that were known to WOMEDA and affected by the degradation of vegetation and soils. The households were selected according to the following criteria agreed between the experts and the research team: 1) smallholder farm households with less than 10 acres of land (4.7 ha) registered in the village offices, 2) who had not received any agricultural training, and 3) who had reported that the fertility of their land had declined since they started farming. The longest-residing families started farming in 1940, and the most recent arrivals began in 2015. With an average of 7.8 members per household, this sample represents about 3% of the farm households in the surveyed wards. We interviewed the head of the household if he or she was around (in 95% of the cases) or, if not, his wife (5%). The questionnaire was conducted in Kiswahili and the local Kihaya languages, contained 55 questions (quantitative, qualitative, open, and closed), and covered two cropping and two dry seasons between September 2016 and August 2017.

Data analysis

We developed an expert-based farm household typology following Alvarez *et al.* (2014). A farm household typology is a snapshot in time and space identifying differences between households according to selected key indicators, in order to come up with different groups (types) of households, in which similar households are gathered within one group (Alvarez *et al.* 2014). We identified the following seven indicators and their thresholds: *land size* (< 1 ha), *banana yield* (< 1 t farm^{-1}), *coffee yield* (< 100 kg farm^{-1}), *livestock* (< 0.2 tropical *livestock units* (TLU)), *trees* (< 10 trees), *potential* labour (< 2 persons day^{-1}), and *hired labour* (0 person day^{-1}). We wish to note here that upon interviewing we found out that some households cultivated more than 10 acres of land, although it was not registered in the local office of the village. In the analysis, we took into account the cultivated land as mentioned in the survey. Households meeting 0–1 of the indicators' thresholds were grouped into Group A, those fulfilling between 2 and 3 indicators into Group B, and those with more than 4 into Group C.

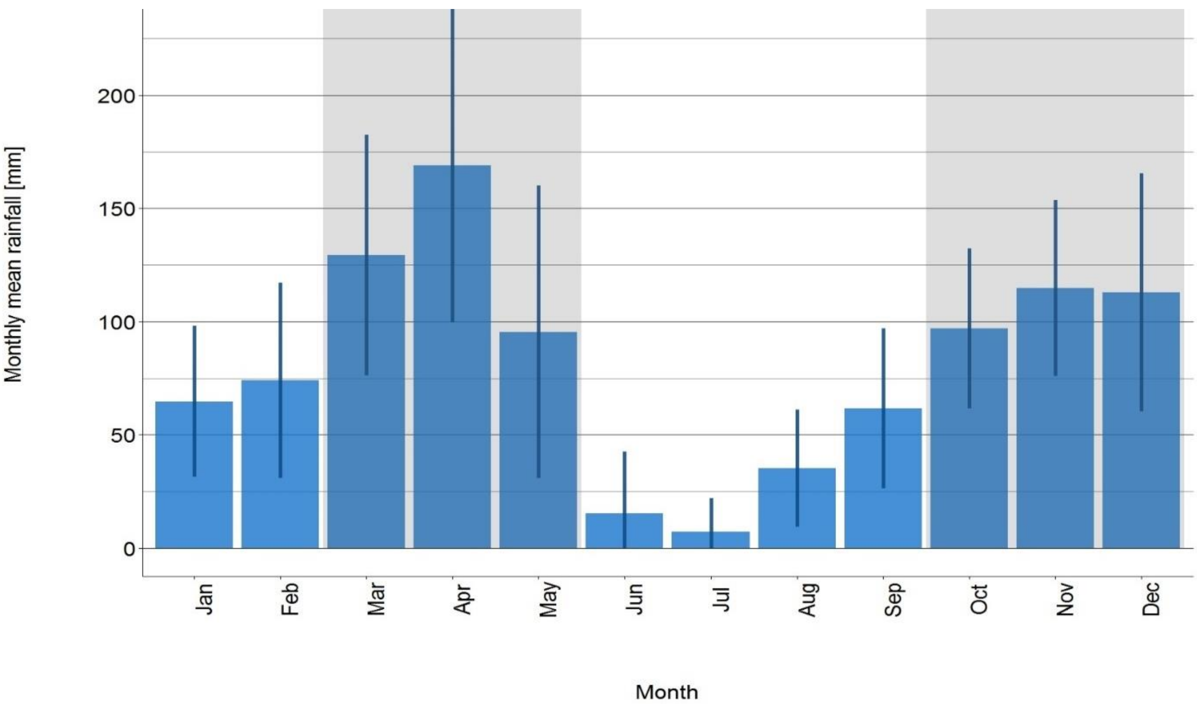

Fig. 2-6: Average monthly rainfall distribution in the period 1981–2014 in Kayanga, Karagwe district, Kagera region, 1,650 m above sea level, with a mean annual rainfall of 982 mm (± 127 mm). Usually, most rain falls from March to May during the Masika rainy season and from October to December during the Vuli rainy season. Source: TMA (2017).

Further variables on farm and household characteristics were analysed as dependent variables. The *age dependency ratio* was calculated according to the World Bank (2017). The *age dependency ratio* describes the ratio of adult household members of working age (defined in this study as between 14 and 50 years) to children (younger than 14 years) and elderly persons (above 50 years), who might require care. A ratio of < 1 indicates that the household has more members of working age than dependents. A ratio of > 1 indicates more dependents living in one household than persons of working age. The *potential labour* describes the labour that is potentially available in each farm household and is measured in persons day^{-1}, where 1.0 persons day^{-1} is the amount of work that can be done on the farm by one adult male between 14 and 50 years in one eight-hour 'shift'. According to this definition, one adult female works 0.7 persons day^{-1}, and a child or person older than 50 years works 0.5 persons day^{-1}. We also assessed the food security of each group of farm households according to the FAO's definition, which involves food availability, access to food, utilisation of food, and stability throughout the year (FAO 2006). The assessment is based on 116 kcal for 100 g cooked banana, 160 kcal for 100 g raw cassava, 119 kcal for 100 g cooked maize, and 166 kcal for 100 g beans according to Lukmanji *et al.* (2008), and assumes that an adult farmer needs 2000 cal per day in accordance with WHO guidelines (2018). Coffee, animal products, sweet potato, yam, and other vegetables are not included in each household's calorie count, and nor are food bought, crops sold, or food storage losses. We excluded sweet potato, yams, and other vegetables from this analysis, as yields were low, and most farmers could not give accurate assessments of their yields of these crops because they harvest them irregularly.

The expert-based typology was validated with multivariate statistical analyses using a principal component analysis (PCA) and hierarchical cluster analysis (HCA). As the PCA is sensitive to outliers and missing values, 25 farm households had to be excluded from the multivariate analysis (*cf.* Alvarez *et al.* 2014). The results of the multivariate analysis were comparable to the expert-based typology; only mean values and standard deviations were lower due to the omitted outliers. In this paper, we present the results of the expert-based farm household typology. Outliers were manually grouped into this typology.

2.4 Results

2.4.1 Farm household typology

Three groups of farm households emerged from the expert-based farm household typology (Tables 2.1 and 2.2). Group A is characterised by relatively high, Group B by moderate, and Group C by low biomass production. In all groups, the coffee yield is the most limiting factor, whereas the potential labour of 2 persons day^{-1} is available in most households.

Table 2-1: Farm household groups (Group A, B, C) and their characteristics according to the indicators and their thresholds as they were applied in the expert-based typology.

Expert-based typology (n = 150)	***Group A***	***Group B***	***Group C***
Biomass production	High	Moderate	Low
Indicators below threshold	0–1	2–3	4–7
Households per group	58	48	44
Percentage of households with indicator below the threshold			
Land size < 1 ha	0	15	80
Banana < 1 t farm^{-1}	10	56	100
Coffee < 100 kg	38	67	82
Total livestock < 0.2 TLU [a]	9	19	61
Fruit trees < 10 trees	7	8	43
Potential labour < 2 persons day^{-1}	7	10	18
Hired labour, 0 persons day^{-1}	2	60	95

[a] Tropical livestock unit (1 TLU = 250 kg). Livestock on smallholder farms in Tanzania refers to 1 cow = 1.3 TLU; 1 goat, sheep, or pig = 0.2 TLU; 1 chicken or rabbit = 0.01 TLU (FAO 2013; HarvestChoice 2015).

Table 2-2: The proportion of the farm households surveyed in each community, and the number of households per identified farm household group.

Population data in surveyed areas of Karagwe and Kyerwa districts [a]							***Surveyed households*** *(n=150)*			
Division	Ward	Village	House-holds	Female population	Male population		Group A	B	C	Total
Karagwe district										
Bugene	Kayanga	Rwambare	427	993	1069		1	0	0	1
	Ndama	Nyabwe-gira	748	2014	2603		2	2	2	6
	Nyaka-hanga	Bisheshe	631	1503	1739		1	3	4	8
Nyaishozi	Nyaishozi	Nyaka-yanja	686	1681	2212		2	4	4	10
Kituntu	Kihanga	Kishoju	645	1976	1859		3	6	4	13
	Kituntu	Kituntu	861	2360	1084		5	7	3	15
	Chanika	Chanika	622	888	1045		8	5	2	15
						∑	*22*	*27*	*19*	*68*
Kyerwa district										
Kaisho	Isingiro	Kihanga	714	1665	1953		4	3	9	16
Mabira	Kamuli	Kamuli	1148	2614	2772		10	4	0	14
	Kikukuru	Mukunyu	568	1373	1816		8	5	2	15
	Kimuli	Kimuli	250	1797	1806		7	3	4	14
Nkwenda	Nkwenda	Kakerere	n. d.[b]	2326	2242		4	2	2	8
	Rukuraijo	Rukuraijo	490	1587	1536		2	6	7	15
						∑	*35*	*23*	*24*	*82*

[a] Population data received from the local offices of the village.
[b] No data.

When compared against each other, agricultural households are wealthiest in Group A, while households in Group B are moderately wealthy to poor, and those in Group C are poorest and most affected by food insecurity. Farm households in Group A have the largest household size, highest labour, land size and yields of banana, coffee, and beans, the most livestock, and also the lowest age-dependency ratio (Table 2-1, Table 2-3 and Table 2-4). They produce similar yields of maize and cassava to Group B, but fewer fruit trees. Households in Group A own twice as much livestock as households in Group B, but both groups keep most of their animals on grassland (open grazing). Although farmers in Groups A and B have a high number of trees, half of them additionally access nearby forests to gather or cut wood.

Most households in Group A are run by men – grandfather, father, or eldest son – and half of the household members are male. Besides this, almost all families in Group A hire additional labour during labour-intensive periods, can easily access local markets to sell their agricultural goods, and half of them earn extra income in off-farm jobs. In contrast to Group B and C, most families in Group A live in brick houses and one quarter of them own improved pit latrines with permanent walls, roofs, and doors.

In Group B, household size, age and gender distribution of the household members are similar to Group A, but more women lead the household (35% compared to 16% in Group A). Significantly fewer households in Group B can afford to hire labour, earn additional income from off-farm jobs, live in brick houses, or have improved pit latrines. They also cannot access local markets as easily as farmers from Group A.

Households in Group C show limitations in all key indicators except in potential labour. They have the lowest biomass production, and most households cultivate less than one hectare (average 0.8 ha), with significantly smaller homegardens. All crop yields are low, and few households produce coffee or possess livestock. Half have about 228 fruit trees, which they use for timber and firewood, and most households additionally access the forest to collect firewood and timber. Half of all female-headed farm households are found in Group C (see chapter 2.4.3).

Each family in Group C has more female members than male, and only 40% of the household members are of working age, i.e., between 14 and 50 years. The *age-dependency* ratio is the highest in this group, which further reduces the potential labour per family. Group C is also the most disadvantaged group regarding hired labour, off-farm jobs, and access to local markets. Moreover, most of the farm households have no motorised means of transport, live in mud houses, and have pit latrines without a permanent roof and walls.

Table 2-3: Descriptive statistics of farm characteristics involving land size and biomass production of each household group deriving from the expert-based typology.

Expert-based typology (*n* = 150)	**Households per group**	***Group A*** 58		***Group B*** 48		***Group C*** 44	
Variable	Unit	Mean/%[a]	S. d.	Mean/%	S. d.	Mean/%	S. d.
Land size							
Land size	ha	4.28	3.13	3.85	6.58	.81	.99
Homegarden	ha	2.81	2.01	1.82	1.84	.64	.65
Woodland	ha	.61	1.00	1.03	4.71	.04	.15
Grassland	ha	.49	.89	.74	2.22	.03	.18
New farmland	ha	.37	.50	.24	.35	.09	.26
Crop yields in the homegarden							
Banana (Musa L. spp.)	t $year^{-1}$	4.21	5.73	1.76	2.52	.19	.17
Coffee (Coffea canephora L. var. robusta)	t $year^{-1}$	.45	.84	.13	.23	.05	.12
Beans (Phaseolus vulgaris, spp.)	t $year^{-1}$	1.47	2.73	.74	.85	.21	.21
Maize (Zea mays L., spp.)	t $year^{-1}$	.61	.86	.68	1.09	.11	.09
Cassava (Manihot esculenta Crantz, spp.)	t $year^{-1}$	.41	.68	.40	.62	.15	.29
Livestock							
Total livestock	TLU [b]	10.3	21.4	4.46	13.3	.55	1.41
Kept in the homegarden	TLU	2.18	3.76	1.53	3.37	.55	1.41
Kept on the grassland	TLU	8.08	21.6	3.18	13.3	.00	.00
Fruit trees in the homegarden							
Total fruit trees	Trees	30.3	27.6	47.1	183	13.0	44.7
Avocado (Persea americana L.)	Trees	10.3	12.8	18.3	71.7	6.42	30.3
Mango (Mangifera indica L.)	Trees	6.31	6.98	14.9	71.6	1.79	2.29
Pawpaw (Carica papaya L.)	Trees	7.21	9.91	4.67	7.64	3.23	12.1
Orange and tangerine (Citrus L. spp.)	Trees	2.41	13.1	1.60	7.40	.21	.60
Guava (Psidium guajava L.)	Trees	1.62	2.86	.94	2.11	.19	.50
Jackfruit (Artocarpus heterophyllus)	Trees	.53	1.47	2.65	14.4	.26	.62
Trees on total land	Trees	1,812	3,163	1,212	4,302	228	1,019
Eucalyptus (Eucalyptus spp.)	Trees	1,381	2,186	821	2,606	218	2.61
Pine (Pinus spp.)	Trees	226	1,043	229	1,448	.00	.00
Umbrella tree (Maesopsis eminii)	Trees	56.0	152	36.3	149	4.65	11.1
Sand olive (Dodonaea angustifol.)	Trees	14.5	28.3	76.9	349	4.12	9.27
Silver oak (Grevillea robusta)	Trees	11.4	33.7	9.96	44.0	.44	1.87
Other trees	Trees	123	791	38.8	145	1.09	3.06
Forest access	Yes, general	21%	-	23%	-	25%	-
	Yes, village	19%	-	29%	-	44%	-
	Yes, both	5%	-	4%	-	5%	-
	No	55%	-	44%	-	26%	-

[a] *Quantitative variables are described with mean value and standard deviation and qualitative variables in %.*

[b] *Tropical livestock units (1 TLU = 250 kg). Livestock on smallholder farms in Tanzania refers to 1 cow = 1.3 TLU; 1 goat, sheep, or pig = 0.2 TLU; 1 chicken or rabbit = 0.01 TLU (FAO, 2013; HarvestChoice, 2015).*

[c] *General land and village land are two different land use categories in Tanzania. Different rights and obligations are connected with each category.*

Table 2-4: Descriptive statistics of household characteristics of each household group deriving from the expert-based typology.

Expert-based typology *(n = 150)*	***Households per group***	***Group A*** *58*		***Group B*** *48*		***Group C*** *44*	
Variable	Unit	Mean/% [a]	S. d.	Mean/%	S. d.	Mean/%	S. d.
Household characteristics							
Household size	Persons hh^{-1}	10.2	7.09	9.65	7.49	5.72	2.37
Gender of head of household	Female	16%	-	35%	-	43%	-
	Male	84%	-	65%	-	57%	-
Age of head of household	Years	51.9	11.1	53.5	12.8	49.7	14.5
Members aged < 14	Persons	3.21	2.78	3.21	2.64	2.81	1.88
Members aged 14–50	Persons	5.95	4.83	5.26	4.83	2.28	1.74
Members aged > 50	Persons	1.10	1.39	1.49	2.16	0.63	0.76
Household members	Male persons	4.46	2.16	4.11	2.88	2.47	1.65
	Female persons	4.39	2.31	3.95	2.10	3.21	1.99
Age-dependency ratio [b]	Dependents working age^{-1}	1.00	0.94	1.61	2.11	2.03	1.78
Economy							
Potential labour [c]	Persons d^{-1}	5.63	2.89	4.99	3.58	3.41	1.61
Distance to market	km	2.88	2.34	3.87	3.19	4.07	3.39
Hired labour	Yes	93%	-	40%	-	6%	-
	No	7%	-	60%	-	94%	-
Off-farm jobs	Yes	55%	-	35%	-	31%	-
	No	45%	-	65%	-	69%	-
Assets							
House	Brick	81%	-	54%	-	28%	-
	Mud	19%	-	46%	-	72%	-
Transport	Car	7%	-	4%	-	2%	-
	Motorcycle	43%	-	15%	-	7%	-
	Bicycle	16%	-	10%	-	10%	-
	None	34%	-	71%	-	81%	-
Toilet	Improved	26%	-	15%	-	6%	-
	Normal	67%	-	85%	-	94%	-
	Flush toilet	5%	-	0%	-	0%	-
Food and water							
Available food [d]	Months	6.60	4.31	3.19	4.14	1.74	3.49
Source of drinking water	Well	6%	-	7%	-	22%	-
	Rain and well	13%	-	24%	-	20%	-
	Rain	9%	-	2%	-	7%	-
	Rain and stream	57%	-	41%	-	24%	-
	Stream water	15%	-	26%	-	27%	-
Drinking water treatment	filter and boil	17%	-	26%	-	14%	-
	Filter	9%	-	2%	-	5%	-
	Boil	52%	-	46%	-	31%	-
	Chemical	2%	-	0%	-	2%	-
	No treatment	20%	-	26%	-	48%	-

[a] Quantitative variables are described with mean value and standard deviation and qualitative variables as a percentage of the studied households.

[b] Children < 14 years and persons > 50 years per working-age household members (14–50 years).

[c] Considering gender and age of household members, with 1.0 pers. d^{-1} per male and 0.7 per female member between 14 and 50 years, and 0.5 per member < 14 and > 50 years.

[d] Number of months in one year in which the household has enough food and is not starving or going hungry, self-assessed by the households.

Despite their comparatively wealthy status, 90% of the farm households in Group A do not consider themselves food secure throughout the year. With an average daily sum of 2338 kcal per person from staple foods and the occasional consumption of meat, milk, eggs and fruit, farmers potentially have sufficient quantities of varied food, assuming that food processing follows adequate knowledge and application. However, this group hardly produces any vegetables, is restricted as to food storage, and does not obtain food at all times of the year. Consequently, this group is food insecure but has a high potential to become food secure.

Group B produces on average a daily sum of 1,340 kcal per person. Again, meat, eggs, milk, and fruit enrich the daily diet, but to a lower extent than in Group A. With only 1340 kcal per person, the farm households do not have enough food to supply all household members, and additionally face the same problems with food storage and accessibility throughout the year. Group B is also not food secure, but might achieve food security by improving agricultural skills and farm management to increase biomass production. Besides this, more households in Group A treat their drinking water before consumption than those in Group B. Three-quarters of the farm households in Group C do not have enough food throughout the year. Group C represents the most vulnerable group of households regarding food security because farm families only produce 450 kcal per person and day. Fruit, and, in a few cases, animal products, enrich the diet.

Farmers might overcome food shortages by buying food or by being paid with food for their labour. However, during the driest months, less labour is needed, which decreases the income of labour-selling households in times when additional income is needed to buy food. As quantity, variety, storage, and availability of food are not sufficient during most months of the year, this group is food insecure. Besides, half of the households do not treat their drinking water, but more of them access drinking water from public wells, despite public wells being often found at longer distances from their farmhouses. To become food secure, the socio-economic status of these households first needs to be strengthened.

2.4.2 Status quo of the farm waste management

Even today, the farm households apply three traditional composting techniques: in situ, pit and ring-hole composting, but to different degrees and with modifications (Tables 2-5 and 2-6). In contrast to this tradition, the application of more than one composting technique without clear separation between *in situ*, pit or ring-hole composting – we call it mixed composting in this paper–is a new development compared to the tradition and affects crop residues, kitchen and food waste, and livestock manure to different degrees (*cf.* chapter 2.2.2).Besides, not all households use or have all types of organic waste; this includes food waste, animal bones, cooking ash, livestock manure and urine, and human excreta.

Table 2-5: Distribution of how the surveyed farm households use organic farm waste in the homegardens, in the percentage of all households (n=150), sorted by current uses and waste fraction.

Current uses	***Crop residues***	***Kitchen waste***	***Food waste***	***Animal bones***	***Cooking ash***	***Livestock manure***	***Livestock urine***	***Human urine***	***Human faeces***
In-situ composting	66.4	36.2	7.4	1.3	19.5	15.4	1.3	25.5	-
Ring-hole composting	2.0	2.7	-[a]	-	1.3	2.0	.7	-	-
Pit composting	9.4	33.6	2.7	.7	20.8	8.1	.7	4.0	-
Mixed composting [b]	16.8	18.8	2.0	-	2.0	25.5	1.3	-	-
Fodder for livestock	.7	6.7	7.4	-	-	-	-	-	-
Self-made pesticide [c]	-	-	-	-	6.0	-	-	4.0	-
Burnt	2.0	-	.7	-	-	-	-	-	-
Not used [d]	2.7	-	-	-	49.7	24.8	71.8	66.4	100
Not available [e]	-		79.9	98.0	.7	24.2	24.2	-	-

[a] *Not used.*
[b] *The term mixed composting is used when farm households use more than one type of composting per waste fraction, e.g., in situ, ring and pit composting for livestock manure.*
[c] *The waste is used as an ingredient for a home-made organic pesticide.*
[d] *The farm households do not use this type of farm waste.*
[e] *The farm households do not have this type of farm waste.*

Following traditional usage, about 67% of the households use crop residues as material for *in situ* composting, especially in Group A. In addition, kitchen waste, livestock manure, cooking ash and human urine are used for *in situ* composting, along with a low percentage of food waste, animal bones, and livestock urine. A few households in Group C burn crop residues by setting fire to the fields. Going against tradition, more households from Groups B and C use kitchen waste as material for *in situ* composting, whereas households in Group A still prefer pit composting. Following tradition, waste pits are rarely opened to distribute the composted material to the fields (in all groups). Only a few households, mainly in Group A, feed kitchen and food waste to any livestock they may have. One-quarter of all households produce no livestock manure.

Another quarter do not use livestock manure as fertiliser, although they have livestock, because they keep it on the grassland and do not collect the manure. The distances between the homegardens and the grassland vary between 0 and 23 km, with an average of 2 km.

Table 2-6: The use and non-use of farm waste in the groups of farm households that emerged from the expert-based typology.

Group of households (households per group)

	A (58)	B (48)	C (44)
<u>Crop residues</u>			
In situ composting [I]	79.3	58.3	58.1
Pit composting	5.2	10.4	14.0
Ring-hole composting	- [III]	4.2	2.3
Mixed composting [IV]	15.5	20.8	14.0
Fodder [V]	-	2.1	-
Burnt	-	-	7.0
Not used	-	4.2	4.7
<u>Kitchen waste</u>			
Pit composting	44.8	27.1	25.6
In situ composting	24.1	39.6	48.8
Rring-hole composting	3.4	2.1	2.3
Mixed composting	17.2	22.9	16.3
Fodder	8.6	6.3	4.7
Not available	1.7	2.1	2.3
<u>Livestock manure</u>			
Not used	32.8	22.9	16.3
Ring-hole composting	1.7	4.2	-
Mixed composting	43.1	25.0	2.3
In situ composting	8.6	22.9	16.3
Pit composting	5.2	10.4	9.3
Not available	8.6	14.6	55.8
<u>Human urine</u>			
In situ composting	13.8	29.2	37.2
Pit composting	5.2	6.3	-
Pit latrine	75.9	58.3	62.8
Self-made pesticide	5.2	6.3	-

	A (58)	B (48)	C (44)
<u>Cooking ash</u>			
Collected in remote place [II]	36.2	50.0	37.2
Pit composting	24.1	12.5	25.6
Ring-hole composting	-	4.2	-
In situ composting	19.0	16.7	23.3
Mixed composting	1.7	4.2	-
Home-made pesticide	5.2	6.3	7.0
Pit latrine	6.9	4.2	7.0
Not available	-	2.1	-
Not used	5.9	-	-
<u>Food waste</u>			
Pit composting	3.4	4.2	-
In situ composting	13.8	4.2	2.3
Mixed composting	1.7	4.2	-
Burnt	1.7	-	-
Fodder	12.1	8.3	-
Not available	67.2	79.2	97.7
<u>Livestock urine</u>			
Not used	87.9	79.2	16.3
In situ composting	1.7	2.1	-
Mixed composting	-	4.2	-
Ring-hole composting	1.7	-	-
Pit composting	-	-	2.3
Not available	8.6	14.6	55.8
<u>Human faeces</u>			
Open defecation	0	0	0
Pit latrine	100	100	100

[I] The traditional use of farm waste is highlighted in bold.
[II] Due to their faith, the farmers collect cooking ashes at a certain place somewhat removed from their farmhouses. Among other beliefs, ash is associated with causing thunderstorms.
[III] Not applied by this group of households.
[IV] The term mixed composting is used when farm households use more than one type of composting per waste fraction, e.g., in situ, ring and pit composting for livestock manure.
[V] If the household uses organic waste as fodder, it is not considered compost material.

Only farmers who keep their livestock in shelters within the homegardens collect manure and use it as compost material. But also, contrary to tradition, dung is not often added to ring-holes, but instead is used for *in situ* and mixed composting. Hardly any farmer uses livestock urine because its collection is even more difficult. Only a few households, who keep their livestock in a shelter, distribute old straw soaked with livestock urine in their homegardens. It is worth mentioning that none of the households buys manure from other farms.

About one third of the households urinate in their homegardens, which is considered as *in situ* composting; with increasing tendency from Group A to C. None of the farmers applies human faeces to the fields. As a rule, human excreta are collected in pit latrines. The sludge in the pit latrines is not used. However, a few households know how to prepare an organic pesticide with cooking ash and human urine and apply it to banana stems or in sugarcane plots to prevent an infestation of pests.

In addition, the majority of the farmers in Groups A and B think that organic material improves soil properties, while this opinion is less prevalent in Group C (65.4%). Most households in every group wish to have more organic material for composting and would like to know more about it. However, only half of all farmers think that mineral fertiliser would improve their soils, and slightly more wish to have access to mineral fertiliser (Table 2-7).

The majority of farmers said initially that they would not use human urine- and faeces-based fertiliser. However, after introducing them to separate toilets for urine and faeces, and to CaSa-compost, most households said they would use both after being trained. The CaSa-compost derives its name from the 'Carbonisation and Sanitation' project established by Krause *et al.* (2015, 2016) during a field trial at the Farmer Field School 'MAVUNO Project' and then further investigated by Krause and Rotter (2017, 2018). Almost none of the households uses mineral fertiliser because it is too expensive, they do not trust fertiliser to work or not to damage their crops and soils, they lack knowledge about the application, or fertilisers are not easily accessible. Few households (under 10%) use chemical or organic pesticides.

2.4.3 Today's gender roles in agriculture

We have further investigated gender-specific division of labour, decision-making and responsibilities on the farm (Table 2-8), outside the farm (Table 2-9), and inside the house (Table 2-10).

Table 2-7: The attitude of smallholder farmers towards the use of and access to organic and mineral fertilisers and their willingness to use fertilisers containing human excreta.

Attitudes in percentage of households *(n = 150)*	*Group A*	*Group B*	*Group C*
Farm households …			
… think that organic fertiliser improves soils	93.1	97.0	65.4
… wish to have more access [a] to organic material	96.6	100	92.3
… wish to know more about how to use organic fertiliser	93.1	100	84.6
… think that mineral fertiliser improves soils	51.7 [b]	54.5 [b]	50.0 [b]
… wish to have more access [c] to mineral fertiliser	58.6	63.6	61.5
Willingness to use …			
… human excreta-based fertiliser	31.0	33.3	11.5
… separate toilets for urine-faeces	93.1	87.9	80.8
… CaSa-compost [d] as fertiliser	79.3	78.8	73.1

[a] Access includes producing and buying of organic materials.

[b] 20.7% of the households responded 'Don't know' in Group A, 15.2% in Group B and 30.8% in Group C.

[c] Access includes cheaper prices, availability at short distances, e.g., local market Access includes lower prices and availability at short distances, e.g., local markets.

[d] The CaSa-compost derives its name from the project called 'Carbonisation and Sanitation', which was established by Krause et al. (2015, 2016) Krause et al.; Krause et al. (2015; 2016) and further investigated by Krause and Rotter (2017, 2018) Krause and Rotter (2017, 2018). It contains sanitised human faeces (15 vol%) mixed with organic kitchen waste and crop residues (15 vol%), biochar residues from micro-gasification of eucalyptus sawdust (17 vol%), wood (21 vol%), ashes, brick particles and soil (31 vol%), and enriched with stored human urine (Krause et al. 2015).

Table 2-8: Gender-based on-farm tasks and responsibilities within the groups of households that emerged from the expert-based farm household typology.

On-farm tasks, decision making and responsibilities in percentage *(n = 150)*

Group of households	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
Households per group	*58*	*48*	*44*	*58*	*48*	*44*	*58*	*48*	*44*
Female-headed households [%]	*16*	*35*	*58*	*16*	*35*	*58*	*16*	*35*	*58*
	Cultivating perennial crops			*Cultivating annual crops*			*Composting*		
Done by women	25.9	35.4	48.8	5.2	25.0	41.9	5.2	20.8	34.9
Done by men	-	-	4.7	44.8	29.2	27.9	29.3	18.8	16.3
Done by both sexes	74.1	64.6	46.5	48.3	45.8	27.9	55.2	49.6	27.9
Not done	-	-	-	1.7	-	2.3	10.3	20.8	20.9
	Producing seeds			*Exchanging seeds*			*Harvesting*		
Done by women	12.1	35.4	46.5	32.8	43.8	48.8	8.6	22.9	41.9
Done by men	1.7	2.1	7.0	6.9	14.6	9.3	-	-	7.0
Done by both sexes	86.2	62.5	44.2	37.9	33.3	20.9	91.4	77.1	51.2
Not done	-	-	2.3	22.4	6.3	20.9	-	-	-
	Livestock-keeping			*Decision on harvest*			*Decision on animal products*		
Done by women	12.1	27.1	32.6	3.4	27.1	41.9	1.7	25.0	34.9
Done by men	8.6	6.3	9.3	13.8	-	9.3	8.6	6.3	7.0
Done by both sexes	72.4	58.3	20.9	82.8	72.9	48.8	84.5	62.5	23.3
Not done	6.9	8.3	37.2	-	-	-	5.2	6.3	34.9

Table 2-9: Gender-based off-farm tasks and trading activities within the groups of households that emerged from the expert-based farm household typology.

Off-farm tasks and trading in the percentage of households *(n = 150)*									
Group of households	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
Households per group	*58*	*48*	*44*	*58*	*48*	*44*	*58*	*48*	*44*
Female-headed households [%]	*16*	*35*	*58*	*16*	*35*	*58*	*16*	*35*	*58*
	Working off-farm			*Selling products*			*Buying food*		
Done by women	6.9	22.9	37.2	3.4	27.1	44.2	17.2	43.8	48.8
Done by men	34.5	31.3	23.3	13.8	2.1	11.6	22.4	14.6	20.9
Done by both sexes	41.4	27.1	32.6	81.0	66.7	32.6	58.6	39.6	27.9
Not done	17.2	18.8	7.0	1.7	4.2	11.6	1.7	2.1	2.3

Table 2-10: Gender-based housework within the groups of households that emerged from the expert-based farm household typology.

Housework in the percentage of households *(n = 150)*									
Group of households	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
Households per group	*58*	*48*	*44*	*58*	*48*	*44*	*58*	*48*	*44*
Female-headed households [%]	*16*	*35*	*58*	*16*	*35*	*58*	*16*	*35*	*58*
	Cooking			*Storing food*			*Collecting water*		
Done by women	94.8	91.7	90.7	63.8	66.7	76.7	77.6	72.9	79.1
Done by men	-	-	4.7	3.4	2.1	4.7	1.7	-	9.3
Done by both sexes	5.2	8.3	4.7	32.8	31.3	18.6	20.7	27.1	11.6
	Washing clothes			*Cleaning the toilet*					
Done by women	93.1	99.6	88.4	72.4	77.1	86.0			
Done by men	-	-	4.7	1.7	2.1	2.3			
Done by both sexes	6.9	10.4	7.0	25.9	20.8	11.6			

The task 'composting' includes the collection of farm waste, the production of rotten material and its distribution onto the field. We have indicated a clear shift in gender roles in farming nowadays compared to the tradition, where responsibilities were clearly distributed between the genders (*cf*. chapter 2.2.1).

In general, today, households tend more to divide on-farm tasks between both genders, with a decreasing gradient from Group A to C. In Group C, a higher percentage of on-farm tasks are completed by women alone, as these households have the highest proportion of female household members. In Group A, both genders or women alone cultivate perennial crops, whereas annual crops are cultivated by both genders or by men alone – which is contrary to tradition.

In all groups, more women are involved in livestock-keeping, although it traditionally used to be a man's business. Composting is often practised by both sexes or only by men in Group A, as it is hard physical work, but the workload shifts towards women in Groups B and C. The harvesting of crops is also shared by both genders in most households in Groups A and B, but with the proportion of women increasing in Group C.

While seeds are produced by both, exchanging seeds is still done to a greater extent by women, but not all households exchange seeds. Decisions regarding what to do with the harvested crops and animal products are mainly taken by both genders or by men alone in Group A – following tradition – but in Groups B and C more women are involved in these decisions.

Although both women and men work off-farm, men do so more often than women, except in Group C (Table 2-9). The sale of products and the purchase of food is carried out by both sexes or solely by men in Group A, whereas, here too, in Groups B and C more women are involved. When it comes to housework, women are much more often involved than men. Housework is rarely divided between the two sexes, especially cooking, and washing (Table2-10) – that tradition has not changed yet.

2.5 Discussion

The identified farm household groups differ significantly from each other in land size, agricultural diversity, labour, market access, food security, wealth, and gender-based distribution of labour, decisions, and responsibilities. In general, male-led households in Group A and B are more productive and wealthier than female-led households in Group C.

Except for Group A, women take on a higher workload on the farm and at home than they would have in the past – a finding that supports observations in the 1990s by Tibaijuka (1994) and Enete *et al.* (2002). Today, in productive households, major on-farm tasks are often shared by both genders and reflect Tibaijuka's (1994) scenarios on labour liberalisation. Farm households in Group C, which have the most female household members and dependents, have the lowest crop yields and limited access to land and livestock. Consequently, women and children are the most vulnerable to food insecurity and poverty, following the worldwide trend (*cf.* FAO 2015; Kristjanson *et al.* 2017). In this disadvantaged group, family members often need to sell their labour to households in Groups A and B in order to survive. As a consequence, they have less time to work on their own farms. We assume that children and teenagers in Group C are more heavily involved in farm work, housework, and decision-making processes than in other groups. We further assume that the health status of these family members is lower than in the other two groups.

Key socio-economic factors for reducing or eliminating poverty are land size, agricultural skills, labour, *age-dependency*, gender-based distribution of labour, food security, medical care, governmental support, and community support for women-led households, as well as social acceptance of the circumstances which have led to women having to run a household alone. Female farmers are additionally less often supported by the community when their husbands have died of AIDS (Kudo 2018). Besides this, we postulate that the outbreak of the HIV/AIDS epidemic in the 1980s led to a reduction in knowledge of on-farm waste management, as the epidemic socially and economically weakened affected farm households (Lwihula *et al.* 1993; Tibaijuka 1997; Appleton 2000; de Weerdt *et al.* 2017; Kudo 2018). The loss of productive generations is often accompanied by a loss of agricultural skills and knowledge, which endangers the food security of future generations (*cf.* FAO 2002).

Land size remains a limiting factor as long as the farm is smaller than one hectare. Otherwise, the influence of land size on biomass production decreases and other factors gain more influence, e.g., labour, knowledge of on-farm waste management, agricultural skills, and income generation. Bidogeza *et al.* (2009) found similar results in Rwanda, in which only farmers with > 1 ha of land adapted to new technologies. Also, the distance between the individual parcels of land that make up one farm has increased over time. This makes it difficult to maintain distant fields.

To this day, composting remains an integral part of farm waste management in banana-coffee-based farming systems, but the potential of using organic farm waste as a fertiliser and soil conditioner is not being fully realised in any of the groups. The beneficial effect of compost application in maintaining or improving soil fertility has diminished for two reasons.

First, not all amounts and types of organic farm waste are used by the smallholder farmers, and therefore not all nutrients are used to sustain soil fertility. This concerns unused human excreta, cooking ash, animal bones, uncollected animal manure and the non-distribution of rotten compost material from waste pits. Krause and Rotter (2017) found similar results concerning human excreta. Human urine and faeces could potentially be used in small-scale biogas production and in the creation of *terra preta*, in which biochar is mixed with organic farm waste and soil material (*cf.* Andersson 2015; *cf.* Krause *et al.* 2015). There is also a need to clarify the safe use of human excreta in farming in terms of hygiene, human transmissible diseases, and crop quality. When the waste pits are dug near the house and not directly on the fields, the nutrients hardly ever reach the plants. In the case of the *in situ* composting of livestock manure, nutrient losses are high due to volatilisation.

Second, degraded soils in the homegardens, in which only one or two vegetation layers grow, do not produce enough organic farm waste to close the nutrient cycle (Baijukya *et al.* 2005a; Bekunda *et al.* 2005). Soil erosion remains high, especially on slopes. We assume that the soil nutrient balances in the homegardens of today's banana-coffee-based farming systems remain in the negative range, especially for households that either have no access to livestock manure or simply do not collect it for redistribution on the fields, and also have no access to mineral fertilisers. Baijukya and de Steenhuijsen Piters (1998) made similar observations in the Bukoba district of the Kagera region, where soil nutrient balances only became positive in homegardens where the system of zero-grazing improved cattle had been implemented. Table 2-11 summarises the nutrient pressures, related environmental hazards and suggestions for measures that could mitigate these problems.

Table 2-11: Nutrient pressures in degraded banana-coffee-based farming systems, related environmental hazards, and measures to reduce nutrient losses and environmental hazards.

Nutrient pressures	***Related environmental and social hazards***	***Measures to reduce nutrient losses and environmental hazards***
Nutrient losses through unused human excreta	Leakage from pit latrines causing eutrophication in water bodies, e.g., Lake Victoria (Scheren *et al.*, 1995)	Safe use of human excreta in agriculture (Andersson, 2015; Krause and Rotter, 2017; Krause and Rotter, 2018)
Nutrient losses through unused crop residues, kitchen waste, ashes, and livestock manure and urine	Soil nutrient mining and yield gaps, increasing poverty (Henao and Baanante, 2006; Tittonell and Giller, 2013)	Safe use of all available (organic) farm waste (Krause *et al.*, 2015; Krause *et al.*, 2016; Krause and Rotter, 2017), and zero-grazing in homegardens (Baijukya and Steenhuijsen Piters, 1998; Kisoza, 2014; Wekesa and Jönsson, 2014)
Nutrient losses through unused coffee hulls	Pollution of water bodies by untreated wastewater from wet processing in coffee factories (Rattan *et al.*, 2015)	Organised redistribution of coffee hulls from factories to villages and farmers for biogas production (Kivaisi and Rubindamayugi, 1996; Kivaisi, 2002; Battista *et al.*, 2016)
Collecting livestock manure from village and land in general	Risk of overgrazing, loss of biodiversity, land-use conflicts, contribution to climate change (Kisoza, 2014)	Zero-grazing in homegardens, protected areas for livestock-keeping tribes, commonly managed pastures and forests (Ostrom, 2015)
Reduction of multi-layered vegetation structure as a nutrient source	Loss of biodiversity, reduction of biomass production, risk of soil erosion, contribution to climate change (Kaihura and Schlingloff, 2016; Madulu, 2004)	Agroforestry with integrated farm waste management to rebuild biodiversity, reduce soil erosion, increase biomass production, and mitigate climate change (Wekesa and Jönsson, 2014)
Using firewood as main biofuel for cooking	Deforestation, overuse of shrubland and forest, loss of biodiversity, risk of soil erosion, contribution to climate change (Wasige *et al.*, 2013; Othieno and Awange, 2016)	Reducing demand for biomass by promoting improved cooking stoves, e.g., microgasifiers (Krause *et al.*, 2015)

In addition, further measures need to be considered, and, where appropriate, implemented and strengthened, e.g., organic pesticide management using human urine and ashes as recommended by Wekesa and Jönsson (2014), or rotations with legumes (Franke *et al.* 2018). The management of plant diseases needs to be fostered, especially in areas where diseases like banana wilt destroy plants and yields (Agricultural Council of Tanzania 2018; Geberewold 2019). In addition to organic fertiliser, selective, plant-specific, well-dosed, and timed application of mineral fertiliser on humus-rich soils – to avoid the leakage of nutrients to water bodies – could balance the nutrient shortage in the short term (Vanlauwe *et al.* 2017). Also, terracing in hilly terrain is rarely applied, as it is labour-intensive, as also described by Bekunda *et al.* (2005) for Tanzania, Kenya, and Uganda. Moreover, water harvesting and storage and the cultivation of drought-tolerant crops, e.g., cassava and sweet potatoes, should play an increasing role for smallholder farming families if they are to adapt to climate change.

2.6 Conclusions and recommendations

In the area under investigation, local knowledge of how to produce organic fertiliser is limited, and farmers do not make use of all the different types of organic farm waste. Farm households belonging to Groups A and B have a relatively high potential to increase their biomass production and to become food secure, whereas disadvantaged farm households in Group C will remain most vulnerable to food security if their land size is < 1 ha and their socio-economic status is not strengthened, and if governmental support remains low.

The most vulnerable people tend to be mainly women and children. The demand for soil nutrients to produce sufficient biomass in the form of food, firewood, and timber for the relatively high population cannot currently be met. Soils will not recover from soil nutrient depletion until the entire potential of organic farm waste as fertiliser and soil conditioner is utilised. Knowledge of farm waste management is lacking due to the demographic shocks the region has experienced – the influx of refugees and the HIV/AIDS epidemic – and this has affected soil fertility and agricultural production. Farm waste management practices can be improved through the distribution of rotten material (organic farm waste), by minimising the volatilisation and leakage of farm waste, and via the application of advanced techniques, e.g., *terra preta*, biochar, CaSa-compost (Krause *et al.* 2015; Verheijen *et al.* 2017). We propose to train smallholder households in farm fertility management and additionally to strengthen the socio-economic status of female-headed households, e.g., in farmer field schools and governmental programmes. However, limited labour remains a major restriction to improving farm waste management. In the future, the safe use of human excreta needs to be fostered in engineering and research. Advanced techniques need to be low-tech, affordable, able to be built by smallholder farmers themselves, and not labour-intensive. Further, an up-to-date material flow analysis of the entire banana-coffee-based system in the Karagwe and Kyerwa districts is needed, including the four land-use types: homegarden, new farmland, grassland, and woodland. Also, waste flows between farm households within or among the groups remain somewhat unclear. Soil samples need to be taken to analyse chemical, physical, and biological soil properties, and samples of organic farm waste must be obtained to estimate its nutrient content and to assess health risks for all household groups.

To avoid labour and knowledge remaining limiting factors, smallholder farmers need to be trained in and advised on sustainable farming, which includes the holding of agricultural yearbooks and labour optimisation. To close knowledge gaps and minimise uncoordinated farm work, the communication culture within families should be improved by implementing a transparent information structure that strengthens cooperation among all family members. Involving all household members in farm work and decision-making processes decreases the risks of yield losses during times of illness. By extension, the community, e.g., a hamlet within a village, could develop a common responsibility on afforestation and farm waste management to create synergies beyond the individual farms, e.g., forest management, or turning coffee hulls and the invasive water hyacinth along the Kagera river into organic fertiliser (Güereña *et al.* 2015).

Our study adds to the scientific community's knowledge of the sustainable restoration of degraded smallholder farming systems in East Africa and may serve as a basis for future development and research. Action needs to be taken involving scientists, engineers, governmental and non-governmental organisations, and institutions at different scales (locally, regionally, or nationally) to contribute towards achieving 'SDG1: No poverty', 'SDG 2: Zero hunger', and 'SDG 15: Life on land' for smallholder farming families, who are responsible for the major part of Africa's agricultural production. Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2020.102915.

2.7 Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

2.8 Acknowledgements

We thank the whole WOMEDA team, especially Juma Masisi, Leinalida Alichard, Harriet Robert and Godson Byamungu, for their close and sincere cooperation, without whom data collection would not have been possible; we appreciate the constant support, honest communication, and fun we had during the fieldwork. Our warmest thanks go to Joana Lapao

Rocha, who always kept her nerve and humour and never gave up during fieldwork. We also cordially thank Sekela Twisa and Mohamed Mwabumba for hosting us in Dar es Salaam, and the MAVUNO Project for their sincere cooperation, for hosting us in Karagwe and introducing us to the Karagwe district, as well as Shadrack Stephene for explaining land-use policies to us and Frederik Baijukya for teaching us how farming systems developed in Karagwe. Lastly, we gratefully acknowledge the United Nations University and the Heinrich Böll Foundation for funding, Claudia Matthias for designing the figures in this paper, and Atiqah Fairuz Salleh and Helen Grützner for their constant support and guidance in the editorial aspects of the paper.

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3 Traditional and adapted composting practices

This chapter has been published as a book chapter.

Reetsch, A., Kimaro, D., Feger, K.-H., and Schwärzel, K. **2020d**. "Traditional and Adapted Composting Practices Applied in Smallholder Banana-Coffee-Based Farming Systems: Case Studies from Kagera and Morogoro Regions, Tanzania." In *Organic Waste Composting Through Nexus Thinking: Practices, Policies*, edited by Hettiarachchi, H., Caucci, S., and Schwärzel, K., 165–84. Cham, Switzerland: Springer Nature.

Traditional and adapted composting practices applied in smallholder banana-coffee-based farming systems: Case studies from Kagera and Morogoro regions, Tanzania

Abstract

In Tanzania, about 90% of the banana-coffee-based farming systems lie in the hands of smallholder farmer families. In these systems, smallholder farmers traditionally add farm waste to crop fields, making soils rich in organic matter (humus) and plant-available nutrients. Correspondingly, soils remained fertile during cultivation for over a century. Since the 1960s, the increasing demand for food and biofuels of a growing population has resulted in an overuse of these farming systems, which has occurred in tandem with deforestation, omitted fallows, declined farm size, and soil erosion. Hence, humus and nutrient contents in soils have decreased and soils gradually degraded. Inadequate use of farm waste has led to a further reduction in soil fertility, as less organic material is added to the soils for nutrient supply than is removed during harvesting. Acknowledging that the traditional use of farm waste successfully built-up soil fertility over a century and has been reduced in only a few decades, we argue that traditional composting practices can play a key role in rebuilding soil fertility, if such practices are adapted to face the modern challenges. In this chapter, we discuss two cases in Tanzania: one on the traditional use of compost in the Kagera region (Great African Rift Valley) and another about adapted practices to produce compost manure in the Morogoro region (Uluguru Mountains). Both cases refer to rainfed, smallholder banana-coffee-based farming systems. To conclude, optimised composting practices enable the replenishment of soil nutrients, increase the capacity of soils to store plant-available nutrients and water and thus, enhance soil fertility and food production in degraded banana-coffee-based farming systems. We further conclude that future research is needed on a) nutrient cycling in farms implementing different composting practices and on b) socio-economic analyses of farm households that do not successfully restore soil fertility through composting.

Keywords: African smallholder agriculture, Banana-coffee-based farming systems, Reuse of farm waste, Composting, Soil fertility and conservation

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H. Hettiarachchi et al. (eds.), Organic Waste Composting through Nexus Thinking, https://doi.org/10.1007/978-3-030-36283-6_8

3.1 Introduction

Increasing yield gaps for almost all crops and decreasing food security are exacerbating poverty in rural areas in Sub-Saharan countries (Tittonell 2013; Tittonell and Giller 2013). In many cases, low biomass production results from soil and land degradation, which in turn are driven or accelerated by three factors: firstly, the growing demand for food of an increasing population; secondly, poor soil and land management; and thirdly, the increasing variability of rainfall pattern due to climate change (FAO 2017a; Gebrechorkos *et al.* 2018; Masawe 1992). In banana-coffee-based farming systems in mountainous regions in Tanzania, smallholder farming contributes up to 95% of agricultural production (*cf.* (FAO 2017a). Mountainous regions in Tanzania are densely populated and intensively used to produce banana (mainly fruit banana and plantain, *Musa spp*.), coffee (mainly *Coffea canephora*), maize, roots, tubers, pulses, and legumes. Since the 1960s, agricultural production in these regions has increased, often in unsustainable ways. For instance, omitted fallows, intensive use of woody biomass in three-stone fires, missing awareness concerning soil erosion measures, frequent tillage, and lack of composting and mulching have resulted in the exploitation of vegetation, land, and soils. In rural areas of Tanzania, such as the Kagera region, more than 90% of the rural households' cooking energy relies on firewood (unprocessed woody biomass) and charcoal (processed woody biomass), and improved stoves are not widely utilised (URT 2012). Due to the poor soil and land management, the amount of organic material added to the soils has reduced compared to the soil status in the 1960s and 1990s (Copeland Reining 1967; Touber and Kanani 1996). This led to a reduction of humus content and plant-available soil nutrients and thus, decreasing agricultural production. Since the extraction of biomass is not compensated by measures to improve soil fertility and nutrient recycling, significant degradation of vegetation and soil, and thus, accelerated soil nutrient depletion and declining water resources occur in the mid and long terms (Schwärzel *et al.* 2017). Furthermore, East African countries have experienced increased unreliability in rainfall patterns in the last decade, and future scenarios show that higher temperatures, less rain, and changes in rain pattern are very likely for some regions in Tanzania (Gebrechorkos *et al.* 2018). Smallholder farmers in mountainous regions in Tanzania, however, depend on rainfed agriculture, and we experienced that only a few farm households have experience with or the capacity of long-term water harvesting to feed the family's demand for drinking water and to irrigate the main farmland. Food production is therefore severely jeopardised.

Traditionally, smallholder farming practices in banana-coffee-based farming systems ensured that a sufficient amount of organic material returns to the soils to produce a thick, dark-coloured, humus-rich, and thus, nutrient-rich topsoil (Copeland Reining 1967; Masawe 1992; Touber and Kanani 1996). As introduced above, unsustainable agricultural practices since the 1960s have led to a continuous reduction in the addition of organic material to the topsoil, and thus, to a reduction of humus content in the soil. With less humus that is able to store and release nutrients, the productivity of these farming systems has diminished. A change in reuse and recycling of organic material from farms is thus needed. Research has shown that the potential of farm waste as a soil fertiliser and soil conditioner is not yet exhausted in banana-coffee-based farming systems because adapted composting practices are not frequently applied (*cf.* Kimaro *et al.* 2011). Furthermore, nutrients contained in human excreta are not widely maximised (Krause *et al.* 2015; 2016). Acknowledging that the traditional use of farm waste successfully built-up soil fertility over at least one century and has been reduced in only a few decades, we argue that traditional composting practices will have to play a key role in rebuilding soil fertility in degraded banana-coffee-based farming systems. To transform degraded banana-coffee-based farming systems into sustainable agroforestry or agro-ecology systems that meet regional and global challenges, the understanding of traditional uses of farm waste is as important as the integration and adaptation of these practices (FAO 2015a, 2017b; Gliessman 2015, 2016).

In this chapter, we focus on traditional and adapted composting practices in banana-coffee-based farming systems to highlight the positive properties of organic farm waste as a soil fertiliser and soil conditioner. In the following, we first describe the characteristics of banana-coffee-based farming systems, and secondly, illustrate traditional and adapted composting practices that are typical for these farming systems. Then, we present two cases where these composting practices are applied. The first case introduces the work of the farmer initiative Mavuno Project in the Kagera region in north-west Tanzania (Great African Rift Valley, Lake Victoria Basin; Fig. 3-1).

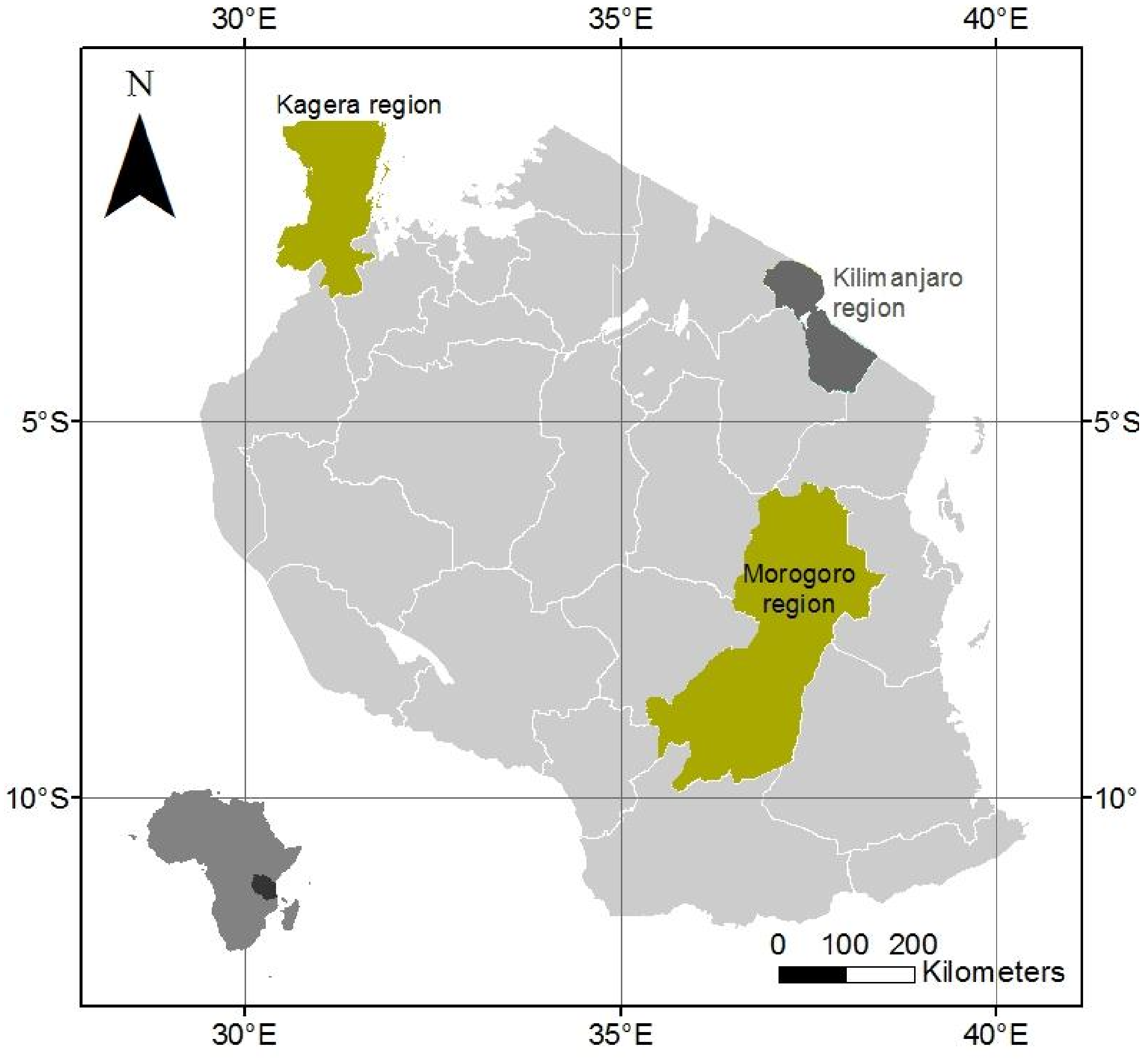

Fig. 3-1: Map of the Kagera, Kilimanjaro, and Morogoro regions in Tanzania (Shapefiles used from Map Library (2007)).

In the Mavuno Project, about 750 smallholder farm families have been trained in implementing adapted composting practices to restore degraded banana-coffee--based farming systems. The second case presents the work of a farmer field school established by the Sokoine University of Agriculture (SUA) in the Uluguru Mountains, in the Morogoro region in central Tanzania (Kimaro *et al.* 2011). Among the skills trained, farmers learnt how to produce adapted *in-situ* and on-surface composting. In the discussion, we compare degraded banana-coffee-based farming systems with densely cropped and well-managed systems in the Kilimanjaro region (north Tanzania), discuss the advantages and disadvantages of the composting practices introduced, and consider their limitations.

3.1.1 Banana-coffee-based farming systems in the highlands of Tanzania

The banana-coffee-based farming system is a typical smallholder, usually rainfed, subsistence farming system based on agroforestry in a tropical, mountainous environment, covering the dominant perennial crops coffee and banana, several annual crops, and native trees (Rugalema *et al.* 1994). Garrity *et al.* (2012) classified it as a typical Sub-Saharan African farming system, namely, the 'highland perennial', indicating that perennial crops—in this case, banana and coffee—are the core of the agricultural production. In Tanzania, traditional banana-coffee-based farming systems are mostly cultivated by smallholder farmer families and consist of up to four subsystems: the homegarden called *Kibanja* (in other Bantu languages named '*Kihamba*', '*Shamba*', or '*Chagga*'), new farmland or land in transition from grassland to farmland called the *Kikamba*, grassland called the *Rweya*, and woodland, the *Kabira* (Baijukya *et al.* 2005a; Copeland Reining 1967; Dancer 2015; C. Hemp and A. Hemp 2008; Rugalema *et al.* 1994, Fig. 3-2).

Depending on the region, the naming of these subsystems differs according to the local Bantu language. In the Kilimanjaro region, the banana–coffee-based farming system is known as the *Chagga* (Hemp and Hemp 2008), named after the dominant tribe, the *Chagga*, that settled on the slopes of the Mount Kilimanjaro. *Chagga* landowners create and maintain densely intercropped and productive homegardens known as K*ihamba* where cultivation is well established. Around the *Kihamba* a small area is set aside for women to grow a variety of vegetables, which include amaranth, cabbage, peas, and tomatoes.

A multilayered vegetation structure (Fig. 3-3), which corresponds to that of a tropical mountain forest with trees, shrubs, and herbs can be found within the Kihamba (Akinnifesi *et al.* 2008). Comparable to the *Kihamba* in the Kilimanjaro region, the *Kibanja* in the Kagera region is the heart of the farming system (Fig. 3-2a).

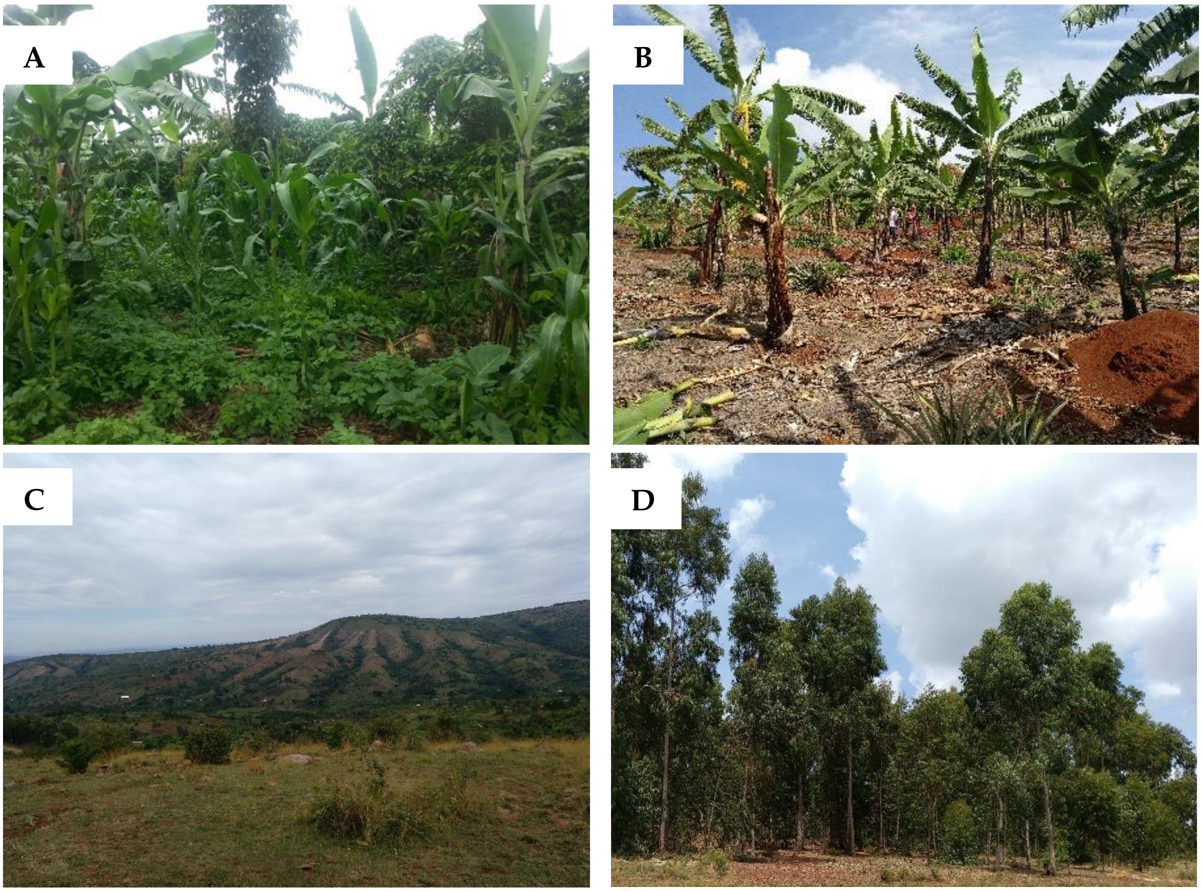

Fig. 3-2: The subsystems of a banana-coffee-based farming system, in the Kagera region, north-west Tanzania. (a) Kibanja, (b) Kikamba, (c) Rweya, (d) Kabira.

Fig. 3-3: Multilayered vegetation in the traditional banana-coffee-based farming system – the Kibanja or Kihamba – in Tanzania. (Based on Rugalema et al. 1994 and Akinnifesi et al. 2008), Design: Claudia Matthias).

In these fields, which usually are the closest to the farmers' homes, biomass production is the highest and thus secures the livelihood of the farm families (Copeland Reining 1967; Rugalema *et al.* 1994). In very densely cropped homegardens under favourable soil conditions, the vegetation corresponds to that of a tropical mountain forest and consists of multiple layers: annual crops (first layer), coffee shrubs and very young fruit trees (second layer), banana plants and younger fruit trees (third layer), and older trees (fourth layer) (Akinnifesi *et al.* 2008; Copeland Reining 1967; Hemp and Hemp 2008; Rugalema *et al.* 1994, Fig. 3-3). The first layer is up to 1 m high. Here, beneath a canopy of coffee bushes and banana plants, a variety of shade-tolerant annual food crops grow, such as beans, cassava, maize, yams, sweet and Irish potato, and also fodder, herbs, and grass. Coffee, medicinal plants and shrubs, and a few species of young trees are found within the second canopy zone, which lies approximately between a height of 1 and 2.5 m. Less commonly cultivated are the perennial crops vanilla, cotton, and sugarcane. The third vegetation layer, with the banana canopy along with other kinds of fruit and fodder trees, is located above 2.5 m and approximately reaches a height of 5 m. Here, various banana varieties are grown, of which plantain, the cooking banana is the primary staple food for the farm households; the sweet finger banana is cultivated as a fruit; and the brewing banana to brew local beer. Above this, the fourth layer is less distinct and more blended together. It contains various kinds of trees delivering shade and fruit crops, for example avocado, mango, pawpaw, jackfruit, and citrus fruits, as well as fodder, timber, and firewood. The shade provided by the trees plays an important role in reducing soil evaporation. The response of bananas to droughts is complex; drought effects are associated with low yields notably 6–8 months afterwards. Besides, stall-fed livestock activities and the cultivation of vegetables in kitchen gardens are common practices in this farming system. The farmer families keep mainly goats, pigs, sheep, and chicken in the homegardens, and in a few cases, improved cattle for milk production (Fig. 3-4).

As local weather conditions vary, several combinations of water-harvesting practices can be considered in agricultural production. In the Kagera region, for example, some farmers gather rainwater in clay containers from the roofs of their houses to irrigate the kitchen gardens, whereas a series of interlinked canals carrying water harvested in the forest on Mount Kilimanjaro, called *Mfongo*, helps irrigate the homegardens of the *Chagga* people in the Kilimanjaro region. There, the canals deliver a convenient source of water for domestic use as well as for irrigation purposes. As coffee and banana require between 900 and 1050 m^3 water ha^{-1} $month^{-1}$ (Baulme 1993), irrigation water is supplied via the canals at intervals of 5–8 weeks, in the case of insufficient rainfall.

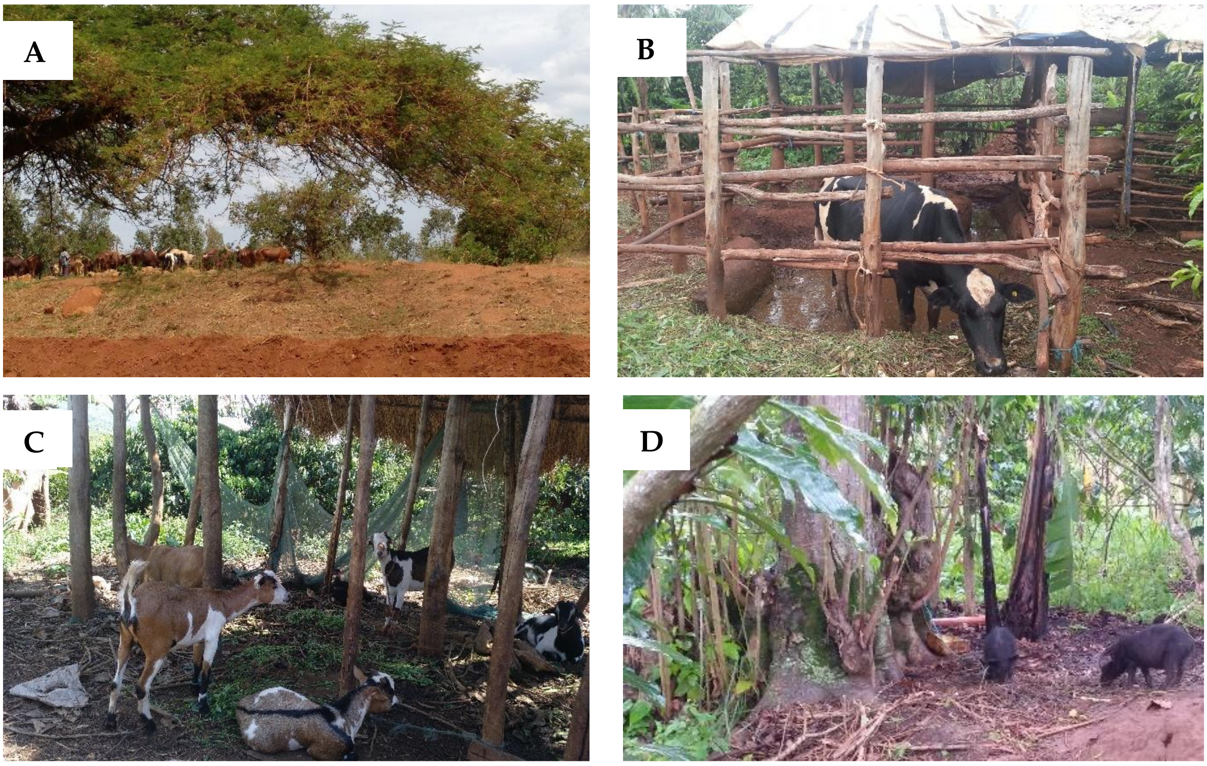

Fig. 3-4: Livestock rearing in smallholder farming. (a) traditional, free-ranged indigenous cattle in the Rweya, (b) integrated livestock management with cowshed for improved cattle in the Kibanja, (c) tied goats under a roof in the Kibanja, (d) free-ranged pigs in the Kibanja.

The other three subsystems are less fertile and diverse. The *Kikamba* (Fig. 3-2b) refers to land transitioning from *Rweya* towards *Kibanja* (*cf.* Baijukya 2004). The original vegetation is gradually replaced by young banana seedlings and some annual crops. Very often, the soils are uncovered and particularly exposed to soil erosion. The *Rweya* (Fig. 3-2c) is grassland and shrubland, which are often used for free-range livestock-rearing (Fig. 3-4). Traditionally, livestock rearing is an essential strategy against food shortage in dry seasons and an additional source of income (Lichtfield and McGregor 2008). The fourth subsystem is the *Kabira* (Fig. 3-2d), a land parcel with trees for firewood, charcoal, and timber production (Copeland Reining 1967).

3.1.2 Composting practices

In the banana-coffee-based farming system, the following kinds of organic farm waste are produced: crop residues, livestock urine and manure, kitchen and food waste, litter, dead wood, ashes (inorganic), animal bones, and human urine and faeces; however, not all kinds of farm waste are used to produce compost, particularly not human excreta (Krause *et al.* 2015, 2016). Since open defaecation is prohibited, human excreta are collected in pit latrines, which are not sealed at the bottom and from which the excreta can easily leak into the underlying groundwater aquifer. Human excreta or pit latrine sludge is not redistributed to the fields. The subsystems of a banana-coffee-based farming system play an essential role in the composting process because farm waste and biomass (grass and wood)—and thus, plant nutrients—circulate within the K*ibanja* and also between *Kibanja*, *Kikamba*, *Rweya*, and *Kabira* (Fig. 3-5).

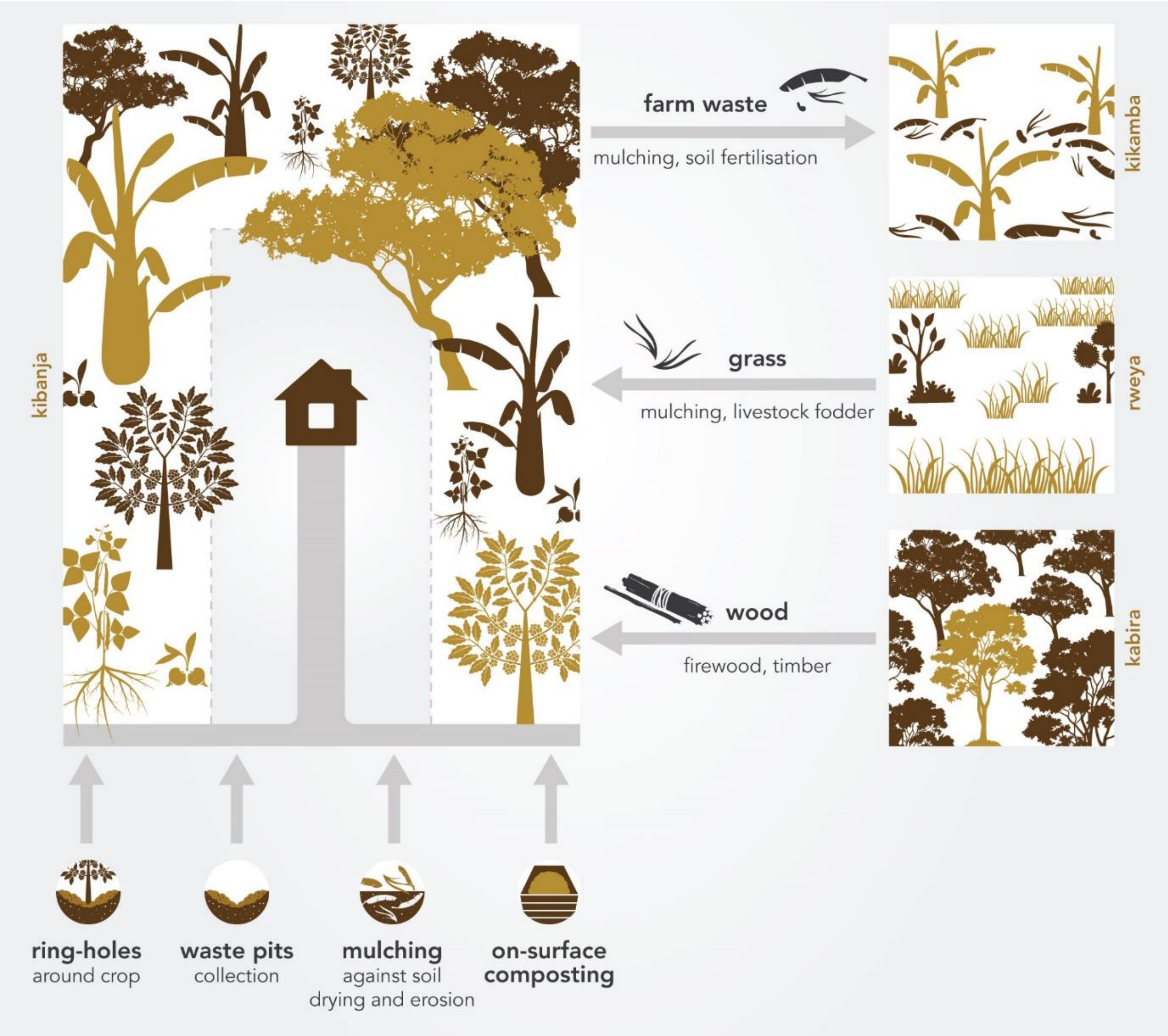

Fig. 3-5: Flows of significant farm waste, grass, and firewood in traditional banana-coffee-based farming systems. (Based on Baijukya and Steenhuijsen Piters (1998, Design: Claudia Matthias).

In general, in the K*ibanja*, most parts of the farm waste usually return to the crop fields, except human excreta, which is gathered in pit latrines on the K*ibanja* land and is not reused. To fertilise the K*ikamba* land and to protect its topsoil against erosion, farmers remove organic material originating from the K*ibanja* and add it to the soils of the K*ikamba* land. From the R*weya*, grass and firewood are imported to the K*ibanja*. The grass is either used as fodder or as mulch. Leftovers of the burnt firewood usually stay in the K*ibanja*. Wooden biomass is imported from the *kabira* into the K*ibanja* and leftovers of the use of wooden biomass usually stay in the K*ibanja*.

3.1.3 Traditional: In-situ and pit composting

In the K*ibanja*, different practices of composting have been developed over the centuries and are still applied by most of the smallholder farmers (Reetsch *et al.* 2020a). The primary practices of traditional composting are ring-hole composting, *in-situ* composting, and pit composting (Fig. 3-6).

Fig. 3-6: Traditional composting practices in banana-coffee-based farming systems in Tanzania: (a) in-situ composting: ring-hole application of livestock manure around perennial crops (banana, coffee), (b) in-situ composting: crop field mulched with plant-based farm waste, (c) pit composting: farm waste mixed in a waste pit. (Design: Claudia Matthias).

As indicated in Fig. 3-6a, farmers dig ring-holes around perennial crops, fill them with nutrient-rich farm waste, preferably livestock manure, and cover the filled plots with soil material (*ibid.*). Another way of composting is presented in Fig. 3-6b. *In-situ* composting comprises of farm waste, which remains in place or can be spread over the surface and left to decompose itself, without any amendments like layering, watering, or adding of ashes (Kimaro *et al.* 2011; Reetsch *et al.* 2020a). During the rotting process of the mulch, humus is accumulated in the topsoil. A third form of reusing farm waste is pit composting (Fig. 3-6c). Very often, farmers collect different kinds of farm waste in pits (Reetsch *et al.* 2020a). After filling these waste pits, they are covered with soil and, if available, grass (*ibid.*). Then, a new pit is dug. Over time, the farmland is spread with pits containing rotten organic waste material. In the homegardens of banana-coffee-based farming systems, the farm waste is composted either *in situ* or in pits (Fig. 3-6). In particular, in-situ composting enables the replenishment of soil nutrients and the conservation of soil moisture throughout the farmland, whereas pit and ring-hole composting improves the soil nutrient status at selected sites.

3.1.4 Adapted: On-surface composting

Traditional composting practices have been modified and further developed as on-surface composting (heap method) by Kimaro *et al.* (2011). This aboveground technique facilitates the production of compost, especially by women and children. The compost pile consists of several layers of farm waste, which are piled on top of each other above the ground (Fig. 3-7).

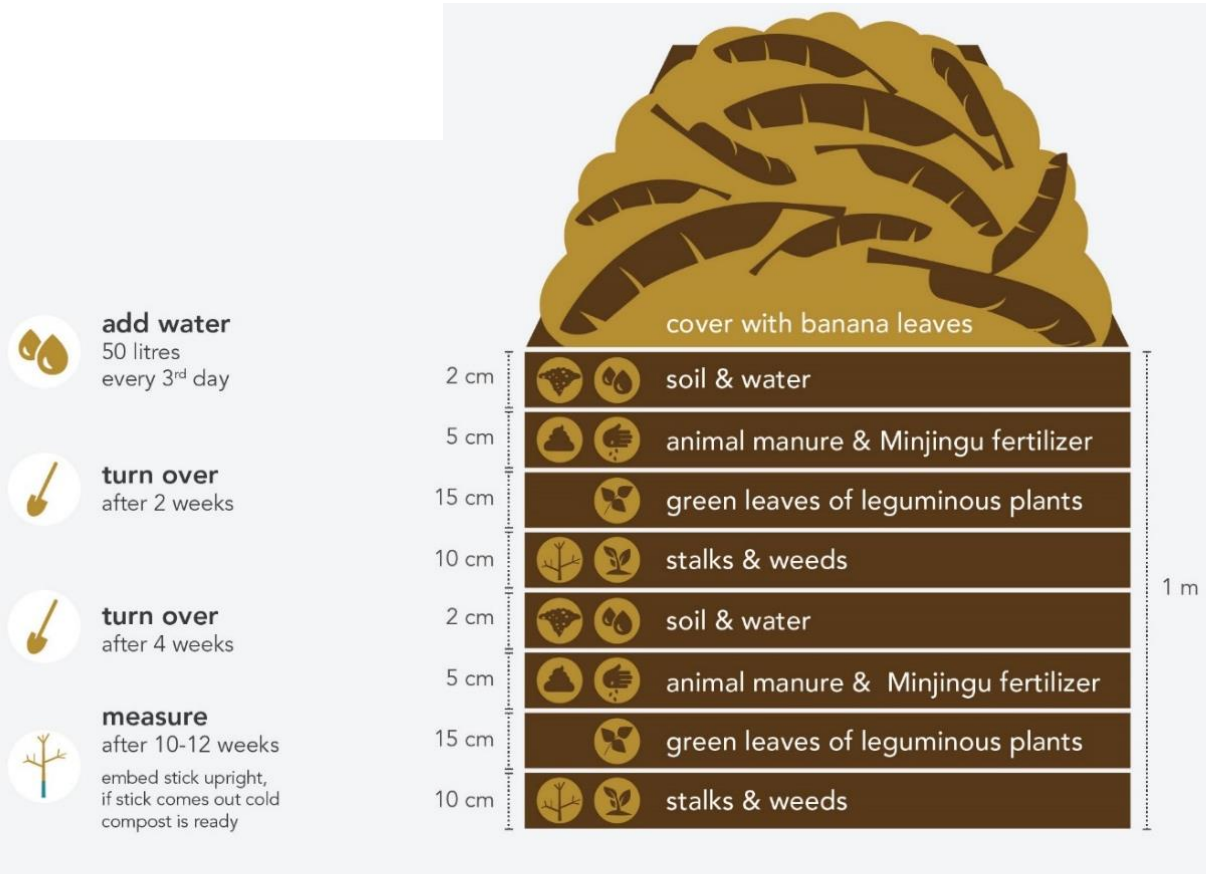

Fig. 3-7: The production of on-surface compost for smallholder farmers in banana-coffee-based farming systems in Tanzania according to Kimaro et al. (2011). (Design: Claudia Matthias).

In the first step, the ground is covered with a plastic sheet to avoid leaching, followed by an approximately 10 cm thick layer of stalks and weed, which forms the base of the compost pile. The second layer consists of green leaves of leguminous plants (15 cm in height) to enrich the compost with nitrogen. The third layer preferably contains animal manure and the local, phosphorus-rich Minjingu rock fertiliser (5 cm in height) followed by a 2 cm soil layer that is moistened with water. The Minjungu rock is mined in the north of Tanzania. All four steps are repeated until a height of approximately 1 m is reached. Finally, the compost pile is covered with banana leaves to control evaporation. To promote the rotting process, the compost pile needs to be regularly turned over. During the rotting process, a wooden stick is pierced through the layers to estimate the core temperature of the compost pile. As long as the rotting process is ongoing, the stick is warm and moist. If it becomes cold and dry, the rotting process is completed.

3.2 Case studies

In this section, we present two case studies on composting in smallholder banana-coffee--based farming systems in Tanzania (Fig. 3-1) that follow each composting practice introduced in the previous section. Both cases are from humid to semi-humid mountainous regions with steep slopes. The first case is located in the Kagera region and the second in the Morogoro region. Both regions suffer from land degradation caused by human activities and climate change as outlined in the introduction (FAO 2017a; Masawe 1992).

3.2.1 Traditional composting in the Kagera region

The Kagera region lies in north-west Tanzania 1,200 m above sea level (asl) (*Fig.* 3-8). The predominant soils are Rhodic and (Anthri-) *Humic Ferralsols*, *Lithic* and *Mollic Leptosols*, *Humic Acrisols*, *Anthri-luvic Phaeozems*, and *Ferralic Cambisols* following the FAO-UNESCO soil classification of 1988 (Touber and Kanani 1996) and recently as *Andosols* by Krause *et al.* (2016).

With an annual rainfall ranging between 800 and 1,000 mm, falling in two rainy seasons, which allows for two cropping seasons per year. However, changing rainfall patterns were reported to cause harvest shocks in the last two decades (Trærup and Mertz 2011). The soils in the Kagera region degraded due to increased rainfall variability, soil nutrient losses, and deforestation—and thus increased soil erosion (Baijukya and Steenhuijsen Piters 1998; FAO 2017b; Trærup and Mertz 2011; Wasige *et al.* 2013)—and changed since 1901 from tropical forest, woodland, and savanna to cropland and pasture (Wasige *et al.* 2013).

Traditionally, the use of farm waste plays an important role in this region (Copeland Reining 1967; Katoke 1970; Ndege *et al.* 1995; Touber and Kanani 1996). Over at least one century, farmers continuously added organic plant material and livestock manure to the fields in the homegardens (Copeland Reining 1967). The warm-humid climate conditions of the region are favourable to decompose organic material within a few days or weeks. This promotes the formation of A-horizons in the soil with a thickness of 30 to 40 cm, rich in soil organic matter and plant-available nutrients (Touber and Kanani 1996).

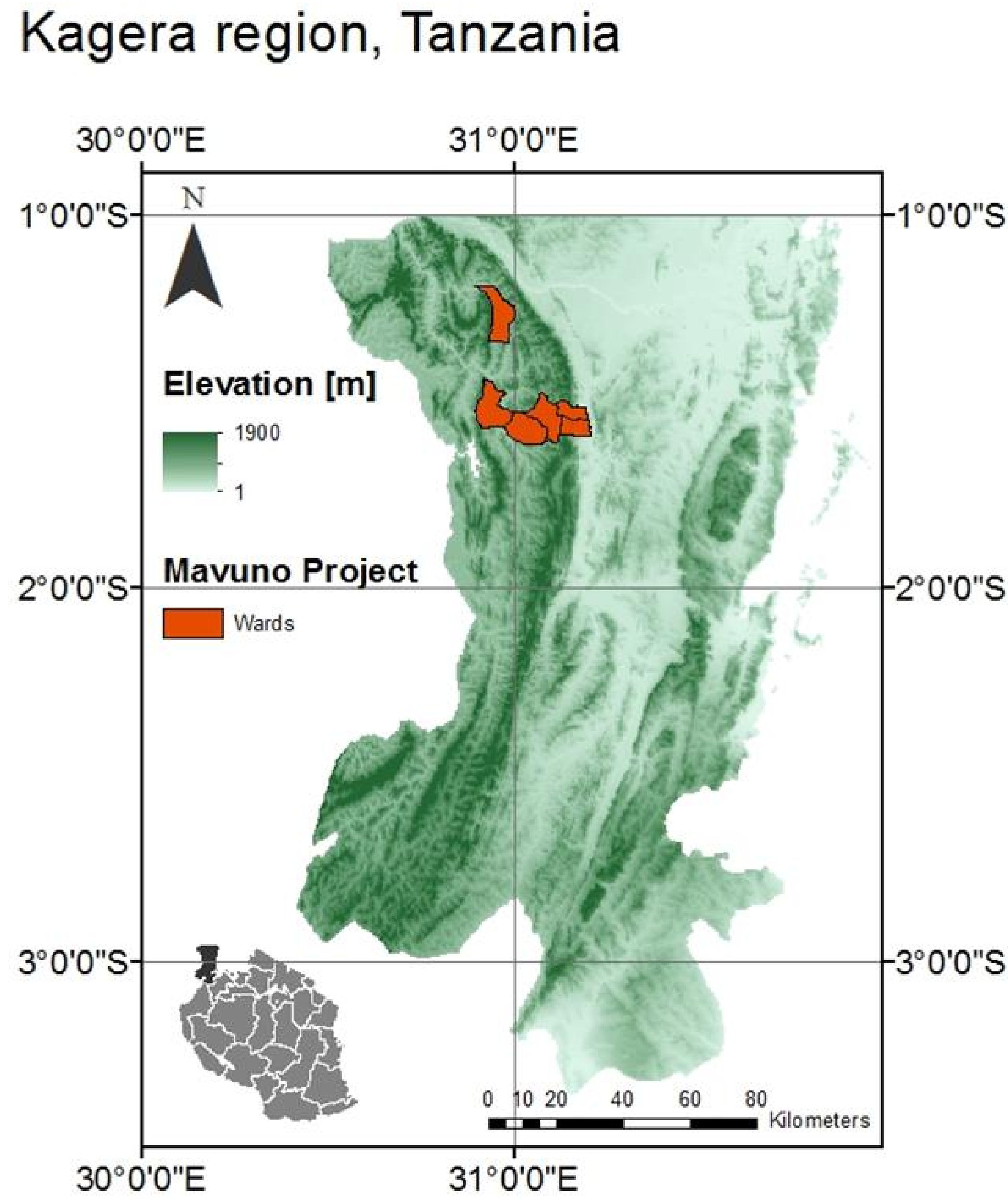

Fig. 3-8: Map of the Kagera region in NW Tanzania with elevation contours (Digital Elevation Model used from CGIAR-CSI (2017)).

Nutrient levels are found to be especially high near the farmers' houses with a decreasing gradient to the borders of the farm [49]. The thickness of the A-horizons decreased over the last five decades because the fields have been intensively used for agricultural production to meet the increasing demand for food and biofuels of the fast-growing and refugee-hosting population (CARE International and Overseas 1994; URT 2016, 2018; Fig. 3-9).

The farmer initiative Mavuno Project (https://mavunoproject.or.tz/wp/) has sup-ported smallholder farmer families in restoring degraded traditional banana-coffee-farming systems and further transforming the *kibanja* into sustainably intensified and climate-resistant farming systems. The agricultural transformation was jointly developed with smallholder farmers acknowledging traditional composting practices, involving climate change adaptation measures, and land management practices that are also known in agroforestry (FAO 2017a; Gliessman 2016; Wekesa and Jönsson 2014). These measures involved nutrient management, soil and water conservation, the establishment of mixed crop-tree systems, adapted agricultural practices (crop rotation, intercropping, relay, and contour strip cropping), tillage, residue management, integrated livestock management, sustainable energy use, and integrated pest management (Wekesa and Jönsson 2014).

Inspired by this smallholder farmer initiative, we investigated the implementation of traditional and adapted composting practices in five focus group discussions with 22 lead farmers working with the MAVUNO Project (Reetsch *et al.* 2020b). The lead farmers were responsible for training and monitoring of 750 smallholder farm families in the Kyerwa and Karagwe districts (Fig. 3-8) in reintegrating traditional composting practices (*cf.* Fig. 3-6) and optimising waste flows within the farmland (*cf.* Fig. 3-5).According to the focus groups, the farm households began by establishing a plot of one acre (0.4 ha) where they planted perennial and annual crops intercropped with a few trees. In this early stage, optimised *in-situ* composting was already practised. With every rainy season, the plot got more diverse, and farmers started to establish further plots. In the discussions, the lead farmers indicated that soil fertility and biomass production increased in those farm households that implemented the composting practices that they were trained on, whereas they did not increase when a farm household did not properly apply the practices taught. As a side effect, humus enrichment counteracted with soil acidification, protected soil water from evaporation, and markedly reduced soil erosion. Increasing soil fertility led to higher yields and higher food availability for the entire farm household. Harvested crops could be stored either for consumption or for sale. However, the first results also indicated that not all farm households succeed in the same way.

3.2.2 On-surface composting in the Morogoro region

In the Uluguru Mountains in the Morogoro region, the mean annual rainfall varies with altitude, from 900 mm at 550 m asl to 2,300 mm at more than 1,500 m asl. In this area, mountain ridges are mainly used for the production of banana, vegetable, bean, and short rain maize while on the foothills long rain maize is the main crop (Kimaro *et al.* 2005). The topography is highly variable with dissected mountain ridges and foothills with very steep slopes of up to 80% and narrow valleys (Kimaro *et al.* 1999). Bedrock geology is dominated by metasediments mainly consisting of hornblende pyroxene granulite, with plagioclase and quartz-rich veins (Kimaro *et al.* 2005).

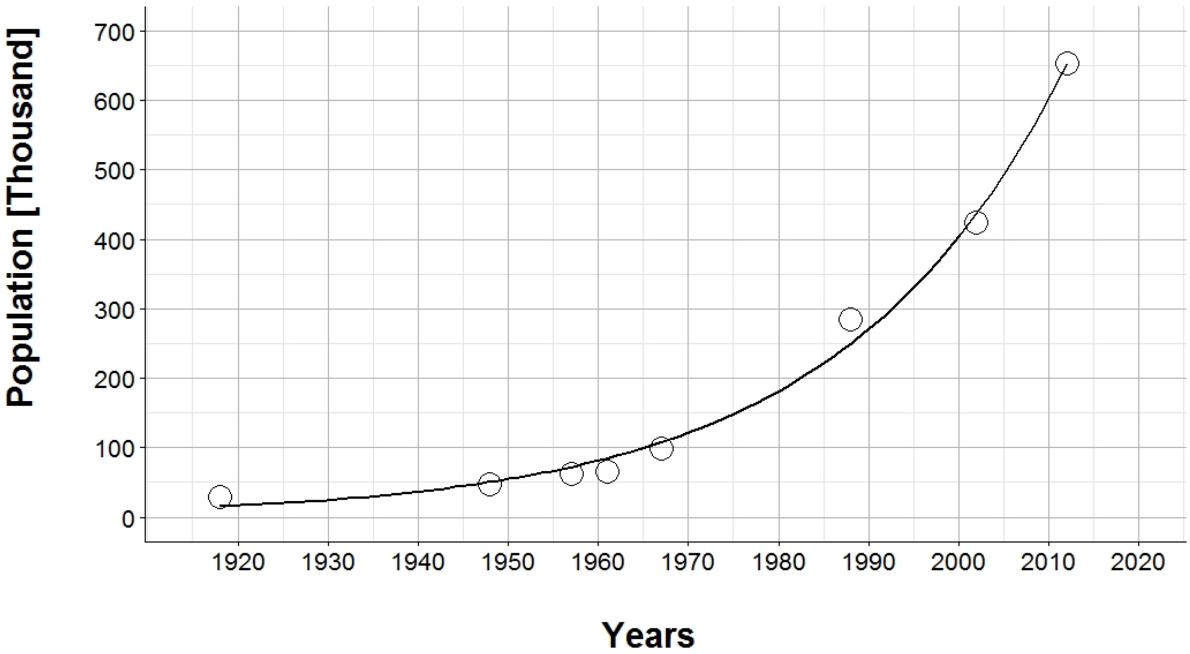

Fig. 3-9: Population growth in Karagwe and Kyerwa district, Kagera region. Data extracted from Copeland and Reining (1967), Katoke (1970), and URT (2016)).

Based on the FAO (2006), the soils on the mountain ridges are dominantly *Endoskeletic* and *Leptic Cambisols*, with accessory surfaces of *Haptic* and *Chromic Phaeozems* and *Orthi-eutric Regosols*. On the foothills, the dominant soils are *Chromic Lixisols* and *Profondic Acrisols* associated with *Hyperferralic Cambisols* and *Endoleptic Cambisols*. The soil covers are generally affected by severe erosion. Increased free-range livestock and human activity have led to the collapse of the soil conservation system and increased land degradation (including soil erosion). Therefore, strategies that aimed at combating land degradation through mechanical and biological measures such as reforestation activities, agroforestry, protection of watersheds, improved land husbandry, and environmental conservation were initiated in Tanzania in the late 1980s (Fig. 3-10; Shetto 1999). The Sokoine University of Agriculture (SUA) initiated a soil and water conservation programme in the Uluguru Mountains to train smallholder farmers on the effect of conservational tillage on soil loss and plant nutrient status on their fields. To that end, a farmer field school was piloted in the north-eastern part (Kimaro *et al.* 2005). The farmers were trained on how to increase the productivity of their farming systems through composting. This included the application of *in-situ* and on-surface composting in combination with conservation tillage and terracing. The results showed that yields under *in-situ* composting and conservation tillage were the highest, presumably due to improved soil fertility and decreased soil losses in space and time (Fig. 3-11; Kimaro *et al.* 2011).

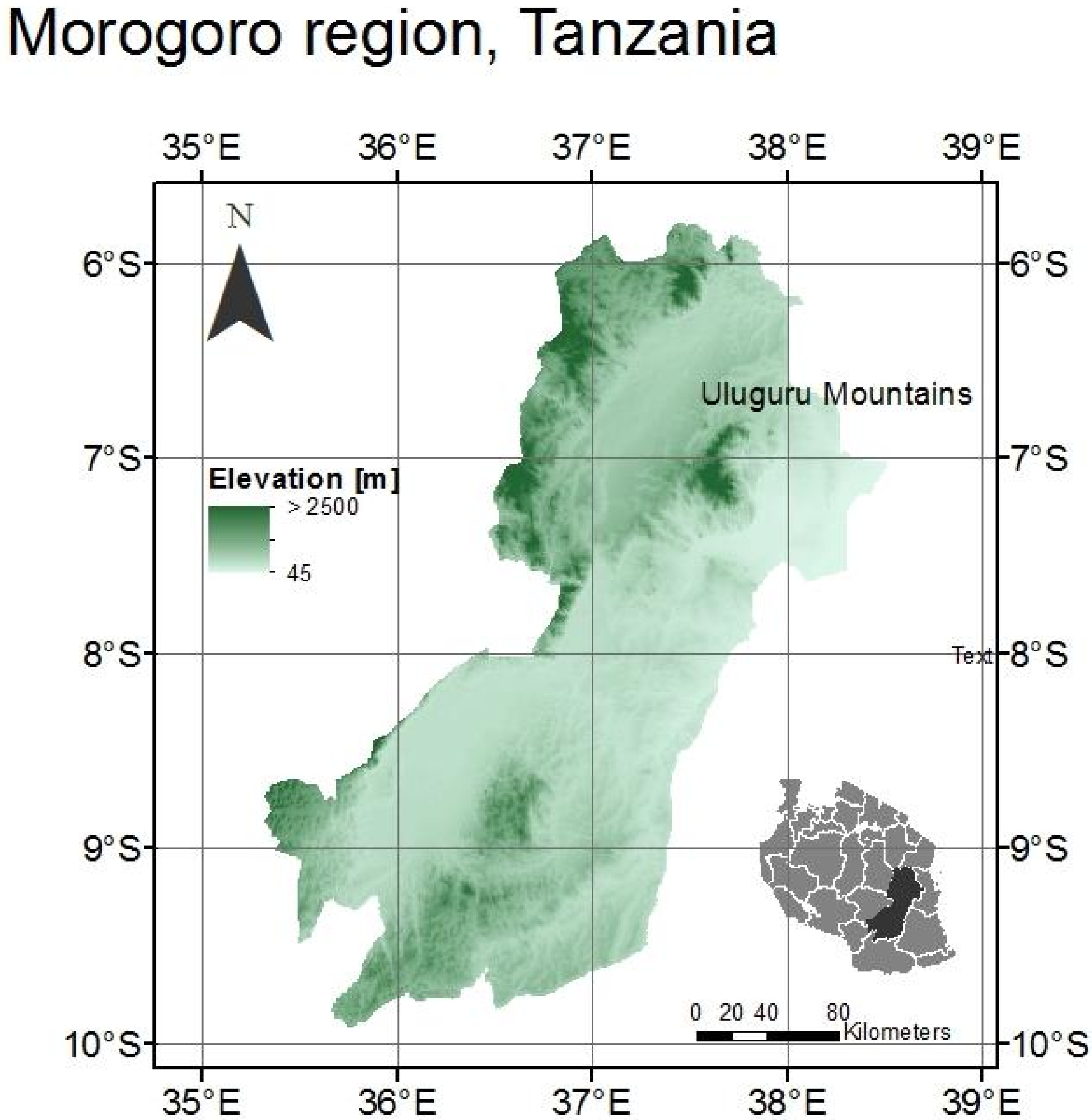

Fig. 3-10: Map of the Morogoro region in central East Tanzania. (Digital Elevation Model used from CGIAR-CSI (2017)).

Seasonal yields of vegetable were measured in order to assess the following soil and water conservation practices: (1) conservational tillage and *in-situ* compositing, (2) traditional terrace and *in-situ* compositing, (3) conservational tillage and manure, and (4) traditional terrace and manure over traditional farming practices. In this case, adapted *in-situ* composting means a mixture of green manure (a mixture of *Gliricidia* and other farm residues at a rate of 5 t ha^{-1}), farmyard manure (10 t ha^{-1}), and Minjingu phosphate rock (MPR) 100 kg P ha^{-1} were left to decompose *in situ* on the soil (Msita *et al.* 2010).

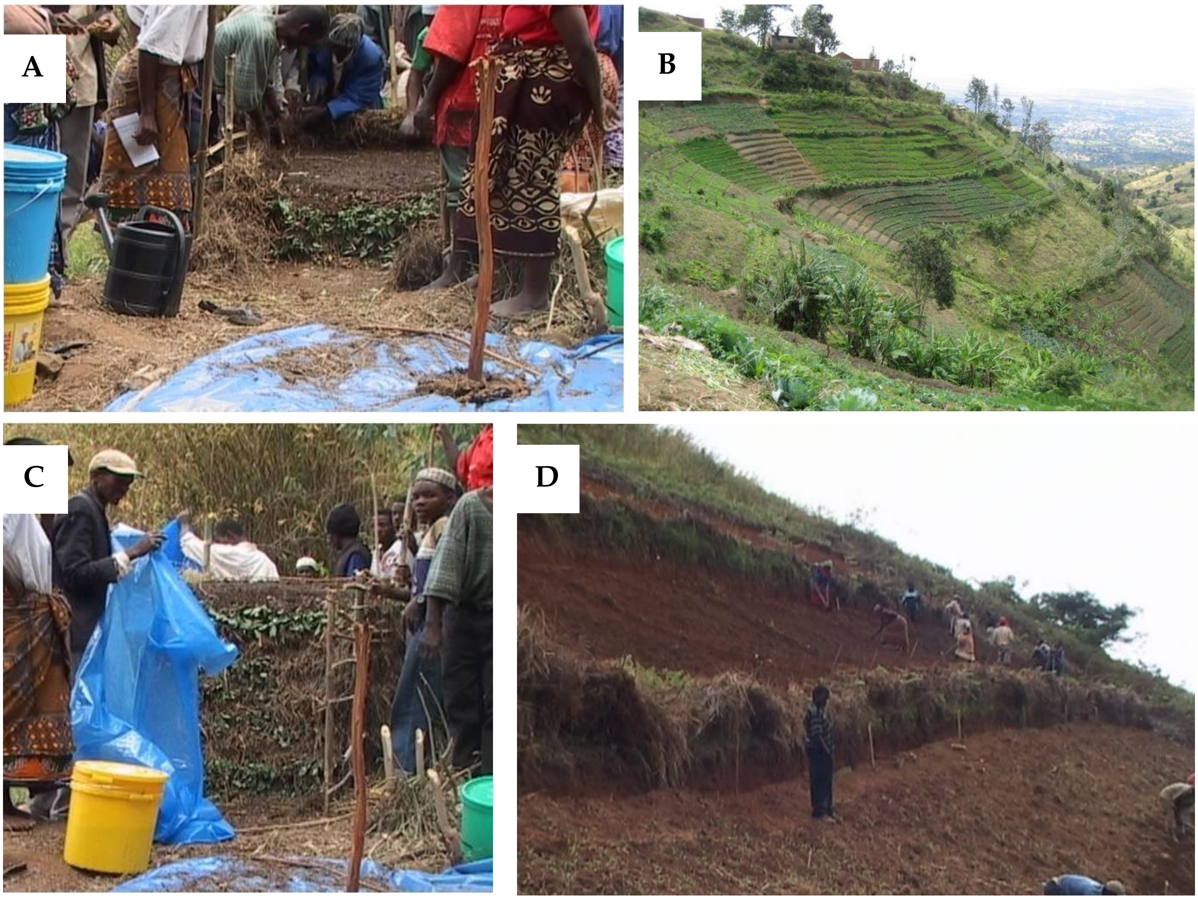

Fig. 3-11: Training farmers on improved indigenous farming practices.(a) and (c) on-surface composting, (b) and (d) traditional terraces (Kimaro et al. 2011).

The results showed that conservation tillage with *in-situ* composting followed by traditional terrace and *in-situ* composting gave a higher fresh yield of vegetables, presumably due to improved soil fertility and decreased soil losses in space and time, than conservation tillage and livestock manure alone, traditional terrace and manure alone, controlled conservation tillage, and controlled traditional terrace (Msita *et al.* 2010). It can be concluded for this case that integrating composting practices in conservation tillage for crop production on sloping land is the best practice for sustainable crop production, nutrient availability, and reduction of soil loss.

3.3 Discussion

As evidenced in both cases, adding compost materials to soils enhances the content of soil organic matter and soil nutrients in degraded banana-coffee-based farming systems. The elevated humus levels increased soil fertility and caused an increase in yield. In the first case, in the Kagera region, previously productive banana-coffee-based farming systems had deteriorated due to rapid land and soil degradation. The desperate attempt to feed and supply the people (locals and refugees from Rwanda and Burundi) with firewood in the 1990s accelerated the loss of biodiversity, thinned vegetation density and the thick, humus-enriched topsoil. However, through reintegration and optimisation of local traditional composting practices, farmers were able to restore soil fertility and thus, to increase biomass production. In our opinion, degraded banana-coffee-based farming systems could reach a high level of diversity through composting. In contrast, in the banana-coffee-based farming systems of the Kilimanjaro region, however, soil and land degradation had been successfully counteracted by composting for several decades (Hemp and Hemp 2008; Kimaro *et al.* 2011). There, biodiversity had been highly maintained with a densely grown vegetation structure of four layers and thus agricultural production systems have remained multifunctional (food, biofuels, cash crops, medicine; *cf.* Fig. 3-3). Degraded homegardens, as presented in the first case in the Kagera region, were less densely cropped with fewer plant species and consisted of only one or two, seldom three vegetation layers (*cf.* Reetsch *et al.* 2020a, Fig. 3-2). In our opinion, multi-layered farming systems in the Kilimanjaro region can be understood as a target state for degraded banana-coffee-based farming systems in the Kagera region (Fig. 3-12).

In both cases, we also observed the challenges and limitations of composting practices. Although composting is often seen as an easily realisable technique, five principles have to be considered to achieve the intended effects (FAO 2015; Kimaro *et al.* 2011; Wekesa and Jönsson 2014). First, not every farming system produces or needs the same kind of compost. In fact, it depends on the biomass produced in the farming system. Second, the materials to produce compost often compete with other uses, for example, with mulching or livestock feeding. Third, climate/weather conditions strongly control the rotting process through moisture and temperature. If it is too dry or too cold, microorganisms may not properly decompose and transform the organic raw materials. Fourth, collecting farm waste and caring for an ongoing rotting process, which includes several turnovers of the decomposing material, and the application of compost to the crop fields is time and labour-intensive. Fifth, the composition and quantity of plant residues differ among crops and, when used in composting, the nutrient composition of the resulting compost material changes as a result.

Besides, the main disadvantage of traditional pit composting is that soils are only punctually enriched with organic matter. The compost material stays in the pit and is not distributed to the crops. As these traditional pits consist mainly of kitchen waste, they are often installed near the farmhouses. Nutrient concentrations are thereby higher in the vicinity of the farmhouses and decrease with increasing distance. However, only numerous rotted waste pits between the crops would bring the soil nutrients to the roots of the crops. Compared to *in-situ* and pit composting, on-surface composting has clear advantages.

Fig. 3-12: Densely grown Kihamba in the Kilimanjaro region.

In addition to the challenges mentioned above, water harvesting will play an increasing role in smallholder agriculture under changing climate/weather conditions (Gebrechorkos *et al.* 2018). Hence, smallholder farmers need to find new strategies to adapt to climate change, not only with regard to soil nutrient recovery but also concerning water harvesting (FAO 2017b).

3.4 Conclusion

The use of farm waste has played a crucial role in traditional smallholder banana-coffee-based farming systems in Tanzania but lost attention since the demand for food and biofuels grew at a faster rate than agricultural production. However, the full potential of farm waste as a fertiliser and conditioner in sustainable soil management is not yet exhausted in traditional smallholder banana-coffee-based farming systems, as composting to our knowledge is not widely practised by all farmers despite efforts to revive it by farmer field schools and other initiatives. In order to keep pace with growing regional and global challenges, traditional composting practices must be adapted and integrated into soil and water conservation strategies (e.g., conservation tillage, terracing, water harvesting). Future research on on-surface composting should, therefore, focus on different compositions and amounts of macro- and micronutrients released from the different kinds of produced composts and should consider the nutrient demand of specific food crops. We further conclude that future research should also focus on the questions: (1) how flows and stocks of nutrients within a farming system change with newly introduced composting practices (*cf.* Fig. 8.5); (2) what are the burdens smallholder farmers, that do not successfully restore soil fertility through composting, have to cope with; and (3) which further practices, for example as part of agroforestry approaches, need to be considered to transform degraded banana-coffee-based farming systems into long-term sustainable and intensive agricultural systems?

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4 Transition towards multifunctional farming systems

This journal article has been submitted to the journal Agricultural System on February 6, 2020 and the revised version on December 8, 2020.

Reetsch, A., Feger, K.-H., Schwärzel, K., and Kapp, G. **2021b**. "Transformation of degraded banana-coffee-based farming systems into multifunctional agroforestry systems – A mixed methods study from NW Tanzania." *Agri. Syst. (under review).*

Modification of organic farm waste management in degraded banana-coffee-based farming systems

Graphical abstract

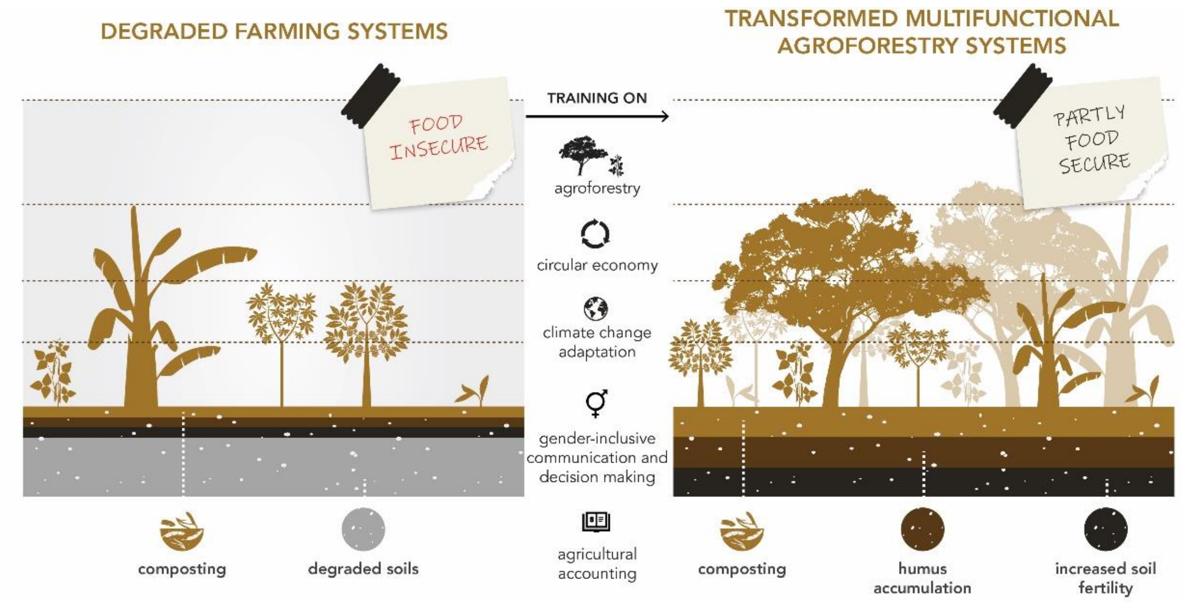

Fig. 4-1: The food security of smallholder farmers is jeopardised in degraded small-scale banana-coffee-based farming systems because agricultural diversity and production are low. Agricultural training helps farmers to convert their degraded farmland into multifunctional agroforestry systems and improves their food security status. (Design: Claudia Matthias and Atiqah Fairuz Salleh)

Highlights

- Training on sustainable land use management (SLM) by farmer field schools (FFS) improves farmers' livelihoods.
- Further development of traditional composting methods, agroforestry and organic pesticide management are key.
- Adaptation to climate change and gender-inclusive communication and decision-making complete the training.
- However, some farmers remain vulnerable to difficulties with food security, income diversification and access to education.
- Mixed methods provide profound evidence of processes and achievements in agricultural research.

Abstract

Soil degradation affects the agricultural production and livelihoods of smallholder farmers in East Africa, especially when land sizes are small, and soil nutrient depletion and crop losses remain high. In this paper, we investigate the progress of smallholder farming households in implementing long-term training in sustainable land management (SLM) in banana-coffee-based farming systems to improve food security in the Kagera region of Northwest Tanzania. The training has been developed by the local Farmer Field School (FFS) MAVUNO Project in cooperation with VI-AGROFORESTRY since the 2000s. The research aims to identify successes, shortcomings, and bottlenecks in the training, and to assess whether and to what extent the multifunctionality of previously degraded farmland could be increased and current challenges overcome. As a first step, we have developed an expert-based farm household typology in five focus group discussions (FGD) involving the 22 trainers, who trained and monitored 755 households. In a second step, quantitative data was collected from the 22 trainers in individual, structured interviews to complement the typology in a convergent mixed methods design. Households that successfully implement the training increase the diversity of both their farms and incomes, improve their food security and education levels, implement gender-inclusive communication, and continue to prosper. Multifunctionality of their farmland is achieved by producing food, fodder, timber, and biofuel for consumption and sale, by providing soil- and water-related ecosystem services, and by adapting to climate change. In comparison to untrained households, successfully trained households produce higher crop yields and improve livestock monitoring, soil fertility and pesticide management. Households that fail to implement the measures remain at a low level of agricultural production and continue to be vulnerable to food insecurity, a lack of income diversification and barriers to education. We conclude that a) mixed methods are advantageous for holistic and time-saving solutions in agricultural research, and b) FFSs significantly contribute to transforming degraded farmland into multifunctional land-use systems, helping to realise SDG 1 (No Poverty), SDG 2 (Zero Hunger), and SDG 15 (Target 15.3: Land Restoration) on a local scale. We recommend focusing future research and technology development on (a) the safe recycling of human excreta for soil improvement, and (b) social structures within the households. We further recommend promoting farmer field schools to continuously institutionalise their knowledge and experiences into community-based and governmental structures, e.g., local governmental offices, the Tanzanian National Land Use Commission (NLUPC), and the Tanzanian Ministry for Agriculture.

Keywords

Land restoration; soil fertility management; climate change adaptation; food security; gender; Water-Soil-Waste Nexus

4.1 Introduction

Soil degradation affects the agricultural production and livelihoods of smallholder farmers in East Africa, especially when land sizes are small and soil nutrient depletion and crop losses remain high (Bekunda *et al.* 2005; Henao and Baanante 2006; Lal 2000; Tully *et al.* 2015). In the highlands of East Africa, banana and coffee are traditionally cultivated by smallholder farmers in so-called banana-coffee-based farming systems (Copeland Reining 1967; Reetsch *et al.* 2020a). The traditional banana-coffee- based farming system in the Kagera region consists of the following four land-use types: young homegardens (*kikamba* in local Bantu language), older homegardens (*kibanja*), grasslands (*rweya*) and woodlands (*kabira*) (Baijukya *et al.* 2005a; Reetsch *et al.* 2020a; Rugalema *et al.* 1994). The homegardens are the most diverse and productive land-use types, where crops, herbs, fruits, medicinal plants, and trees for timber and firewood grow, and livestock is kept (*ibid.*). The vegetation in the homegardens extends over four layers with annual crops above-ground to 1 m height, higher growing annual and young perennial crops (1 to 2,5 m height), perennial crops and fruit trees (2.5 to 5 m height), and older trees for timber and firewood production (above 5 m height, *ibid.*). These farming systems remained productive and biodiverse until the 1960s, mainly through frequent composting of organic farm waste (Copeland Reining 1967; Katoke 1970; Ndege *et al.* 1995; Touber and Kanani 1996).

Today, the Kagera region is affected by severe environmental degradation for several reasons (Baijukya and Steenhuijsen Piters 1998; Reetsch *et al.* 2020a, 2020c). Among them are an increasing demand for food and firewood of a rapidly growing, refugee-hosting and HIV/AIDS-affected population. Kagera was one of the first regions worldwide to be struck by HIV/AIDS in the 1980s, and the population still faces the resulting social and economic constraints (Frumence *et al.* 2010, 2011; Kudo 2018; Kwesigabo 2001; Rugalema 1998). Besides, the region has experienced a massive influx of refugees since the early 1990s due to the persecution of the Tutsi in Rwanda and Burundi and the prolonged war in the Democratic Republic of the Congo (Alix-Garcia and Saah 2010; Ruiz and Vargas-Silva 2018; Whitaker 2002). These two 'shocks' have led to accelerated deforestation, overexploitation of arable land, reduction of vegetation cover, increase in soil erosion and degradation, and the loss of labour and agricultural knowledge in HIV/AIDS-affected households (Alix-Garcia and Saah 2010; Berry 2008; FAO 2017; Wasige *et al.* 2013).

Our previous research revealed that smallholder farmers in the Kagera region still use the traditional composting practices: *in situ*, ring-hole, and pit composting (Reetsch *et al.* 2020a, 2020b, 2020c). In *in-situ* composting, organic waste such as crop residues and kitchen waste are distributed on the ground of the homegarden (*ibid.*). This practise has a mulching effect in addition to the accumulation of humus, soil organic matter and nutrients in the topsoil (*ibid.*). In ring-hole and pit composting, organic farm waste is collected in a hole (ring or pit) and covered with earth (*ibid.*). However, the full potential of organic farm waste in sustaining soil fertility is not fully realised by the farmers today (Reetsch *et al.* 2020a). The reasons are manifold, e.g., insufficient collection and preparation of fresh farm waste, late and insufficient distribution of rotten compost material due to limited labour and socio-economic constraints (*ibid.*). Also, the level of biodiversity and adaptation to climate change in agriculture is low, which results, for instance, in low quantity and quality of farm waste as feedstock for composting (*ibid.*). Besides, the whole region degraded in vegetation density, diversity, and soil fertility due to the higher demand in food and firewood of the rapidly escalating density of a population plagued by disease. The lack of food security and the care for ill family have resulted in a revaluation of priorities within the families. Nutrient management of soils and crops has a direct impact on food and fuel production but lost importance when hunger and disease prevail (Reetsch *et al.* 2020c; Tittonell and Giller 2013). Poverty has increased and is likely to increase further if climate change is not tackled (FAO 2017). Prolonged droughts delayed starts to the rainy seasons, and intermittent rainfall are also having an increasing impact on the region (FAO 2017; Gebrechorkos *et al.* 2018). Poor smallholder farmers face more constraints in increasing crop yields and diversifying agricultural production and are more likely to be affected by weather extremes than wealthier farming families, e.g., through droughts or irregular and unexpected rain patterns (Franke *et al.* 2019; Lichtfield and McGregor 2008; Tittonell and Giller 2013).

To escape this spiral of food insecurity and poverty, the local Farmer Field School (FFS) MAVUNO Project aims at restoring the multifunctionality of today's degraded banana-coffee-based farming systems since the early 1990s. Referring to the concept of multifunctionality in land-use systems proposed by Zhang and K. Schwärzel (2017b), multifunctionality includes *'diverse demands on agricultural land that are met by the production of several goods and services, either on one land-use type or several land-uses on one piece of land, assuming that each action has a function, and that ecosystem services are provided at the same time'*. In this sense, the FFS has established training on sustainable land management (SLM) in cooperation with diverse international organisations and research institutes to regain the multifunctionality of previously fertile homegardens in banana-coffee-based farming systems, and to cope with the current challenges of small farm sizes, food insecurity, and climate change.

In the early 2000s, a few leading farmers became trainers at the FFS and started to train farmers in their neighbourhood. To date, they have trained and monitored 755 smallholder farm households in of the Karagwe and Kyerwa districts in the Kagera region. In the first year, farmers implemented a set of SLM measures including agroforestry, livestock-keeping and monitoring, and integrated organic farm waste and soil fertility management on a trial plot of 0.1 ha. With every cropping season, farmers were encouraged to transform more farmland and to implement measures to tackle pesticide management, soil and water conservation, afforestation, agricultural accounting, marketing, communication, work allocation, time management, and gender-inclusive communication and decision-making. Besides, in a field trial at the same FFS, Krause *et al.* (2015, 2016) and Krause and Rotter (2017, 2018) developed 'CaSa-compost' (Carbonisation and Sanitation compost) by integrating biochar with sanitised human excreta (chapter 4.2.2). In the future, the production and use of CaSa-compost is to become part of the SLM training.

The research presented in this paper aims to identify successes, shortcomings, and bottlenecks in the SLM training and to assess whether and to what extent the multifunctionality of previously degraded homegardens has been increased and current challenges overcome. To assess the progress of trained households, we have asked the following two research questions in this paper: (A) How do trained households differ from one another and from untrained households in terms of (i) land size and agricultural production, (ii) farm waste management, (iii) economy, (iv) food security and drinking water, (v) climate change adaptation, (vi) gender-inclusive communication, (vii) education, and (viii) energy use? (B) What improvements, challenges, and bottlenecks exist, what lessons have been learnt, and what further development is needed? As an overall goal, the research intends to help smallholder farmers to restore degraded farmland, enhance food production and to encourage similar initiatives by FFS.

4.2 Materials and methods

4.2.1 Study area

The study area is located between 1.0° and 2.1° S and between 30.4° and 31.4° E and covers the following wards in the Kyerwa and Karagwe districts of the Kagera region: Chonyonyo, Ihanda, Bugene, Kayanga, Mabira and Rwabwere (Fig. 4-2). The Nyambo-Haya is the most abundant local tribe, and its traditions determine agriculture to this day (Copeland Reining 1967; Katoke 1970; Reetsch *et al.* 2020c). In the geological Karagwe-Ankolean System, altitudes vary between 1,200 and 1,650 metres above sea level (asl). The area is characterised by a bimodal rain pattern, two corresponding cropping seasons, an annual precipitation of 982 mm (± 127 mm), and moderate temperatures with minimum mean temperatures between 12°C and 16°C and maximum between 25°C and 28°C (TMA 2017; Touber and Kanani 1996). In the hilly terrain, soil properties vary with the location, and prevalent soil types are *Andosols*, *Ferralsols*, *Leptosols*, *Acrisols*, *Cambisols*, and *Phaeozems*; in river terraces *Fluvisols*, *Gleysols* and *Planosols*; and in swamps *Histosols* (Krause *et al.* 2016; Touber and Kanani 1996).

4.2.2 CaSa-compost

The CaSa-compost derives its name from the project called 'Carbonisation and Sanitation', which was established by Krause *et al.* (2015, 2016) on a field trial at the FFS MP, and further investigated by Krause and Rotter (2017, 2018). Following Krause *et al.* (2015), the CaSa-compost is produced as follows: first, in urine-diverting dry toilets (UDDT), human urine and faeces are separately collected (*ibid.*). The urine is then stored in closed cans in the sun for two months, which sterilises it (*ibid.*). The solid human excreta and toilet paper, if any, are separately stored to dry for two to four weeks. Then, the dry excreta are heated in a loam oven between 65 °C and 75 °C for 30 to 120 minutes; this achieves thermal sanitation through pasteurisation (Krause *et al.* 2015). The heat is provided by microgasifiers, which are also used for cooking (*ibid.*). Afterwards, in a compost heap, the sanitised faeces (15 vol%) is mixed with organic kitchen waste and crop residues (15 vol%); biochar residues (17 vol%) from microgasification of eucalyptus sawdust; wood (21 vol%); ashes, brick particles and soil (31 vol%); and enriched with the stored human urine (*ibid.*).

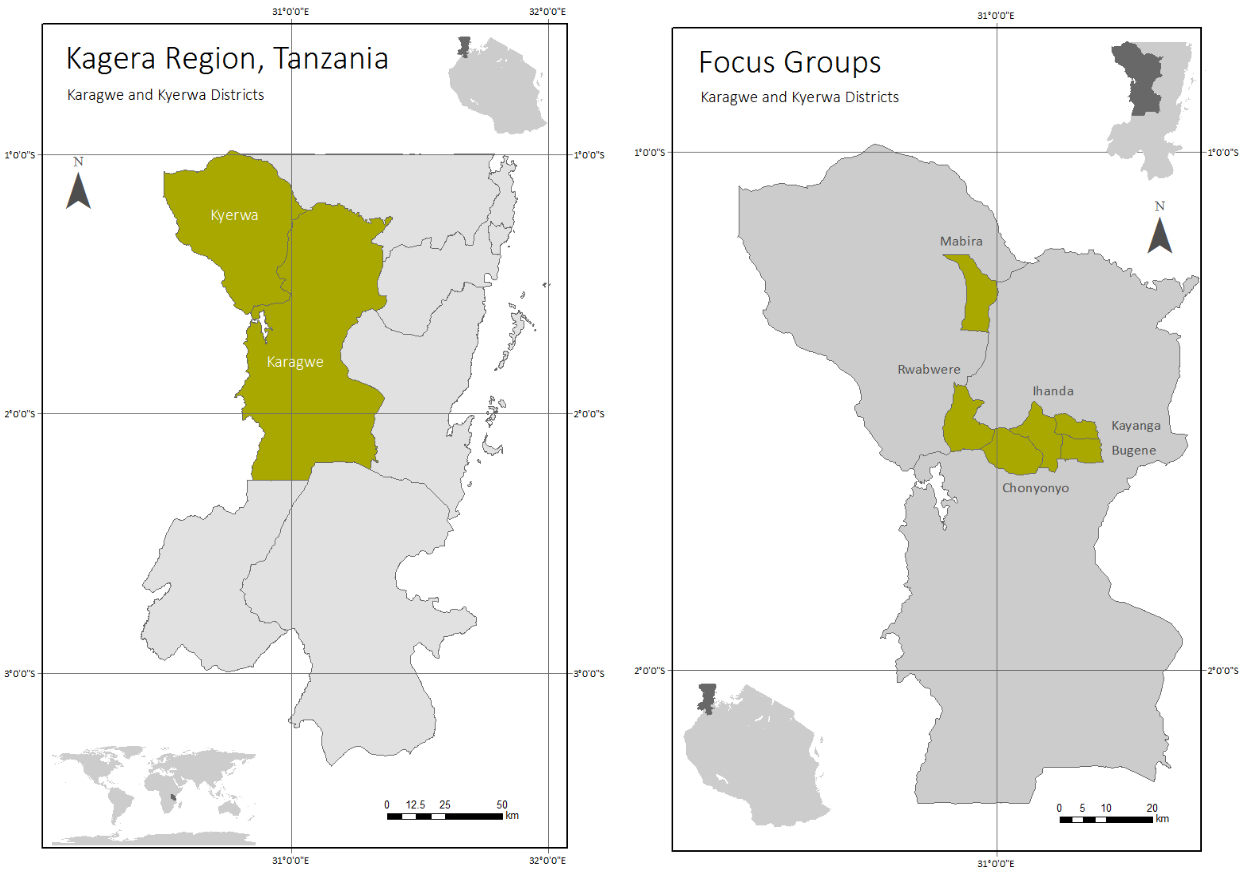

Fig. 4-2: Maps of the study area. The left-hand map shows the Kyerwa and Karagwe districts in the Kagera region in NW Tanzania. The right-hand map shows the wards where the focus group members and trained smallholder farmers live. (Shapefiles taken from Map Library, 2007)

In the field trial, he CaSa-compost was added to an Andosol in which several crops were planted, e.g., beans and maize (Krause *et al.* 2016). This amendment resulted in a significant increase in total above-ground biomass of 211% compared to the control sample (from 1.6 to 3.4 kg m^{-2}), and an improvement in chemical soil properties, i.e., pH_{KCL} increase from 5.3 to 5.9 and phosphorus (P_{cal}) increase from 0.5 to 4.4 mg kg^{-1} (*ibid.*).

4.2.3 Data collection

Following Creswell (2015), we applied a convergent mixed-methods design, in which qualitative and quantitative data were combined. According to definition, *'a convergent mixed-method design involves the separate collection and analysis of quantitative and qualitative data. The intent is to merge the results of the quantitative and qualitative data analysis'* (Creswell 2015). Since the 1960s, mixed methods have developed in health science tending towards a sophisticated methodology, which is increasingly applied in other disciplines, integrating quantitative and qualitative research (Plano Clark and Ivankova 2016; *cf.* Pluye and Hong 2014).

Qualitative data was collected over five focus group discussions (FGD) following Finch *et al.* (2014) and Ritchie and Ormston (2014). In September 2017, five FGDs were organised by the research team at the main office of the FFS MAVUNO. The research team involved the lead researcher, a local agro-economist acting as facilitator and translator, and a technician. The researcher and facilitator guided the discussions by acknowledging local cultural communication habits. The technician was responsible for video and audio recording of the discussions. In the FGDs, all 22 trainers came together to develop an expert-based farm household typology to find similarities and differences among the 755 trained households following Alvarez *et al.* (2014). The trainers were between 30 and 65 years (average 43 years) and equal in their job hierarchy, sharing the same responsibilities within the FFS, and all spoke Kiswahili. Seven of them were female and 15 were male. Four to five trainers formed one focus group. Following Finch *et al.* (2014), we divided each FGD into four sections: the introduction, opening topic, main discussion, and closing topic (Fig. 4-3).

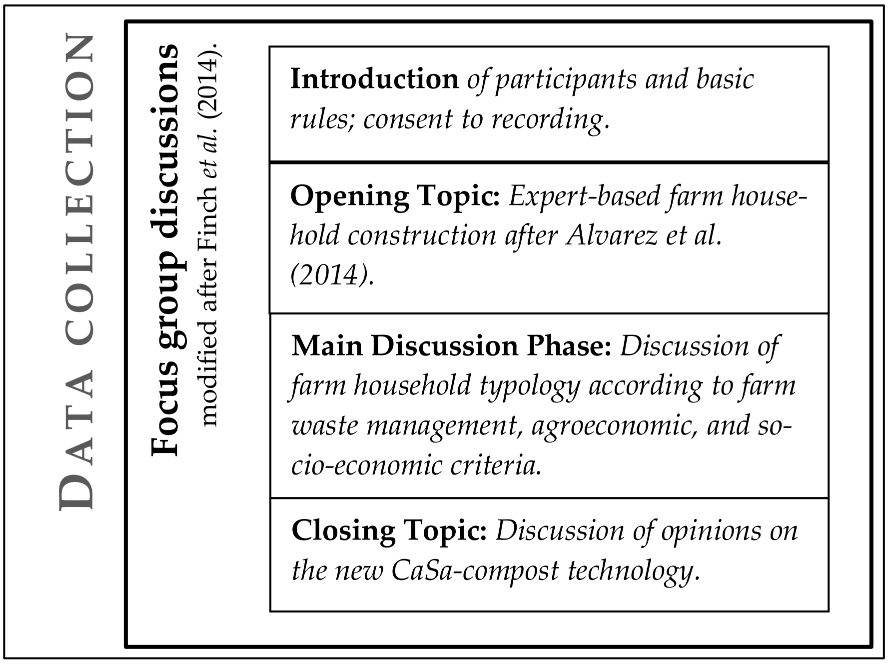

Fig. 4-3: Four stages of FGDs, according to Finch et al. (2014).

In the introduction, basic rules were set, which included active listening, active participation in the discussion, equal rights of all focus group members, and equal value of their opinions. In the opening topic, each focus group was asked to characterise the households they have trained by answering the question: 'Based on your experience, according to which criteria would you group the trained households?' This opening question served as the basis for the expert-based typology construction. In the main discussion phase, the focus groups were asked to add the following characteristics (later called variables) to each identified group of households: land size, agricultural production, farm waste management, inputs, socio-economic conditions, skills, food, drinking water, climate change, gender-inclusive communication and decision-making, and energy. In the closing topic, the group members were asked: 'Would you recommend using the CaSa-compost (chapter 4.2.2) for all household groups?' The FGDs provided an open and trustful setting, including honest exchange and the debating of negatives, which is a prerequisite for the application of FGDs.

The FFS MAVUNO Project (mavunoproject.or.tz) had established a rigorous evaluation and assessment system to monitor the trained farmers and their farms. As soon as the desired objectives were not achieved, discussions were sought with the farmers and solutions worked out by consensus. This approach had been developed by the FFS and was supported, promoted, and researched by international organisations and institutions such as VI Agroforestry, Engineers Without Borders, and the Technische Universität Berlin (Krause *et al.* 2015, 2016; e.g., viagroforestry.org; Wekesa and Jönsson 2014). Unfortunately, a large part of the data was not available in digital form, but as handwritten records. Then, we collected quantitative household and production data for each identified group of households in individual, structured interviews with the 22 trainers following the methodology of Yeo *et al.* (2014). The quantitative data comprised information on socio-economic characteristics, agricultural production, and organic farm waste management. We validated the quantitative answers of the 22 trainers in two steps. First, in cooperation with staff of the NGO VI Agroforestry, we cross-checked about half of the answers with paper-based data. Second, we visited about 15% of the farmers and monitored their farms.

We consider 'mixed methods' to be appropriate for this case study for three reasons. First, we see equal value in qualitative and quantitative data for this topic and for answering the research question, as each quantitative data set has a 'story' behind it, i.e., the social side (*cf.* Creswell, 2015). We accessed and combined the trainers' and the farmer's knowledge – the story behind each trained household and their experiences as trainers – during the FGDs. Second, we evaluate the quantitative and qualitative data as being scientifically sound, as we accompanied the trainers in the field and gained insight into internal documents and records for validation. Third, in a short period of time, this 'inexpensive' approach has enabled us to obtain extensive information about the content, processes, successes, and failures of the SLM training. The results presented in this paper represent the state of the art of the 755 households and sought to describe the process of how the training attending farmers succeed in implementing the SLM training.

4.2.4 Data analysis

The FGDs were transcripted by the facilitator following the transcription rules after Bryman (2016, Fig. 4-4), and were afterwards translated into English. A whole group analysis was applied following Spencer *et al.* (2014), in which each FGD was regarded as one unit without investigating the interactions between single group members. In a qualitative content analysis after Mayring (2014, Fig. 4-5), an inductive coding system was applied for the opening and closing topics, and a deductive coding system for the main discussion phase. Inductive coding is also called "open coding", in which code structure and codes develop from the context of the analysed texts (Mayring 2014). In deductive coding, the code structure and codes are given by the scientist (*ibid.*). Repetitions and redundancies of coded text passages were deleted, and, if appropriate, code categories were merged.

DATA PREPARATION

Transcription & Translation
modified after Bryman (2016)

Transcription rules:
- *Write down what you the focus group members said, no matter whether you agree with it or not.*
- *Anonymise the focus group members.*
- *Avoid any interpretation, analysis, or assessment.*

Translation:
- *From Swahili to English.*
- *As literal as possible.*

Fig. 4-4: Transcription and translation rules for focus group discussions, according to Bryman (2016).

Each code category was shortened, paraphrased, summarised, and further consolidated into the following four main categories: 1) to 3) specific characteristics of three identified groups of households, and 4) similarities and differences between all groups. The main categories were summarised and interpreted. Then, the quantitative interview data was analysed and compared to the results of the FGDs by applying the convergent mixed methods design according to Creswell (2015).

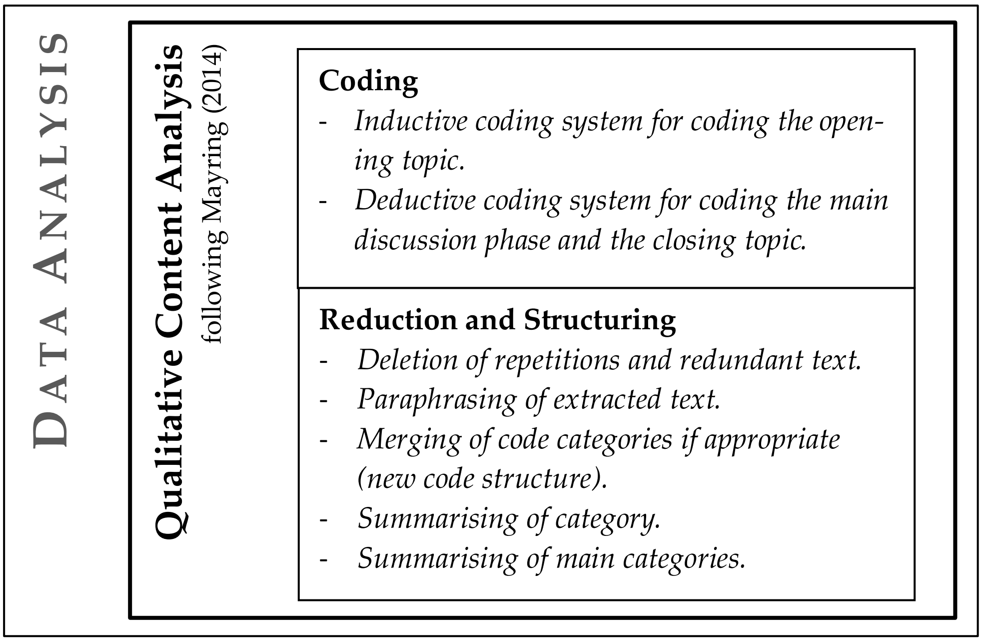

Fig. 4-5: Steps of the qualitative content analysis to analyse the transcripts of the focus group discussions, according to Mayring (2014).

In a final step, the results were compared to the study of (Reetsch *et al.* 2020a, 2020b), who investigated the *status quo* of agricultural production and farm waste management in 'untrained' smallholder farm households – who had not received training in SLM – in the Karagwe and Kyerwa districts. The *status quo* data was collected by our research team in a survey of 150 heads of smallholder farm households of banana-coffee-based farming systems carried out between September and November 2017 and published in Reetsch *et al.* (2020a). The data set was based on a questionnaire containing 54 open and closed questions on household data, agricultural production, and the use of organic farm waste, asking the farmers to recall two growing seasons from September 2016 to August 2017 (12 months). All households were affected by the degradation of vegetation and soil resources and reported that the productivity of their soils had declined since they had started farming. None of the farmers applied mineral fertilisers to the soil and none had received training in sustainable land use management.

4.3 Results

In this chapter, we first present the smallholder farm households typology that emerged from the FGDs. Secondly, we describe the implications of the SLM training, while comparing similarities and differences between the household groups. To ease the discussion, we directly compare the results with untrained households studied in our previous research (Reetsch *et al.* 2020a). Finally, we raise the remaining challenges and bottlenecks.

In the second state of the FGD, the trainers have identified three groups of households according to four key indicators. To give an indication of the tone of the discussion and to give an example of the qualitative data, the following excerpt of the opening topic is introduced:

> *Our understanding of agroforestry farming involves three subcomponents: crop farming, livestock-keeping, and tree planting […] in the same area. […]. We have farmers who adopt what they were instructed, and farmers who do not implement the training unless they observe it from other farmers. […] The farmer group implementing all the skills is placed first (performs well), while those implementing a half to three-quarters of the skills are placed second (perform averagely), […] while those who implemented nothing from the skills are placed third (do not perform well).*

The four key indicators are the implementation rate of the training, completeness of the agroforestry system, income revenue, and food security (Table 4-1). The indicator completeness of the agroforestry system is further divided into crop farming, livestock-keeping, and tree planting. Group A comprises transformed households, Group B constitutes households in transition, and Group C consists of non-transforming households.

4.3.1 Group A: Successful farm households

Households belonging to Group A implement the SLM training, are self-motivated to change their behaviour and traditions, follow the instructions of the trainers, and search for advice in challenging situations. As a result, households have successfully implemented high diversity of crops and trees, and have implemented zero-grazing in the homegardens, are regarded as high-income earners (1,363 UDS yr^{-1}, Table 4-1), who meet their families' needs at any time of the year, and are food secure.

Agricultural production and food security

They maintain well-managed homegardens with an average of 1.4 ha of land, of which they have transformed 0.4 to 0.8 ha into densely grown, multi-functional agroforestry systems (Table 4-2). On the same land, farmers produce food, fodder, timber, and biofuel for consumption and sale.

Table 4-1: Summary of farm household groups and their main characteristics, developed by trainers in the first stage of the FGD (opening topic). All data refers to one farm households.

Expert-based typology	***Group A***	***Group B***	***Group C***
Transformation towards multifunctional agroforestry systems	Transformed	In transition	None-transforming
Implementation rate of the training	Completely	Partly (half to three-quarter)	Insufficient (less than half to nothing)
Completeness of the agroforestry system			
Crop farming	High diversity with over 12 crops.	Lower diversity with up to 10 crops.	Very low diversity with up to 3 crops, often only one crop (e.g., banana or beans).
Livestock-keeping	Over 10 to 20 indigenous cattle in open grazing.	Up to 10 indigenous cattle in open grazing.	No indigenous cattle.
	1 to 10 improved cattle in a permanent shelter.	0 to 3 heads improved cattle in a temporary shelter.	No improved cattle.
	Up to 20 goats, 5 sheep, 3 pigs, 20 chicken and 10 rabbits in a permanent shelter.	Up to 5 goats, 3 sheep, 2 pigs, 10 chicken and 5 rabbits in temporary shelter.	Up to 15 goats tying or open grazing and 5 chicken sheltered overnight in the farmhouse.
	Up to 3 beehives.	Up to 3 beehives.	No beehives.
Tree planting	100 to 200 shrubs and trees.	50 to 100 shrubs and trees.	0 to 50 shrubs and trees.
	Planting of up to 10 native trees in every season.	Planting of up to 5 native trees in every season.	No planting of new seedling or trees.
Income revenue	High, about USD 1,363 yr^{-1}.	Middle, about USD 590 yr^{-1}.	Low, about USD 230 yr^{-1}.
Food security	Food secure for 12 months yr^{-1}.	Food secure for 5 to 11 months yr^{-1}.	Food secure for 0 to 4 months yr^{-1}.

The diversity of crops and trees is high as farmers cultivate banana, coffee, beans, maize, cassava, yams, sweet potatoes, sorghum, groundnuts, fodder plants, medicinal plants, fruit trees, and plant up to 10 seedlings of indigenous tree species for timber and firewood production in every rainy season, e.g., sand olive (*Dodonaea angustifolia*) and umbrella tree (*Maesopsis eminii*). They frequently mulch their fields with grass. In tiny, drip-irrigated kitchen gardens, the families also grow vegetables in small quantities, e.g., amaranth, cabbage, onion, tomato, carrots, aubergines, and okra. The drip irrigation system is constructed of plastic bottles. Some households produce honey.

Table 4-2: Averaged agricultural production of the farm household groups that have emerged from the expert-typology during FGD compared to data collected in individual interviews and untrained households studied by Reetsch et al. (2020c), including average values of homegarden size, households characteristics, crop yields of main crops and livestock husbandry per trained households.

Data emerged from …		***… focus group discussions***			***… individual interviews***			***… untrained households*** [I]		
Group of farm households	**Unit**	*A*	*B*	*C*	*A*	*B*	*C*	*A.1*	*C.1*	*Mean*
Number of farm households	hh group^{-1}	n. d.	n. d.	n. d.	296	262	198	58	44	150
Homegarden size										
Homegarden	ha (average)	0.6-2.8 (1.4)	0.4-1.0 (0.7)	0.2-0.8 (0.5)	1.1	0.7	0.4	2.8	0.6	1.8
Transformed homegarden	ha (average)	0.4-0.8 (0.6)	0.1-0.4 (0.2)	≤ 0.1	0.5-0.8	0.1-0.4	0.1-0.0	d. h.	d. h.	d. h.
Household characteristics										
Household size	pers. hh^{-1}	n.d.	n.d.	n.d.	5.3	5.1	5.1	10.2	5.7	8.5
Female-headed	% of hh	n.d.	n.d.	n.d.	30	29	33	16	43	31
Labour spent on the farm	hours adult^{-1} day^{-1}	n.d.	n.d.	n.d.	7.6	6.7	5.1	n. a.	n. a.	n. a.
Meals	meals day^{-1}	n.d.	n.d.	n.d.	3.0	2.2	1.7	n. a.	n. a.	n. a.
Crop yields										
Banana (Musa spp.)	t homegarden^{-1} yr^{-1}	11-50	2.8-18	0.7-1.2	46	13	3.4	4.2	0.2	2.1
Coffee (Coffea canephora)	t homegarden^{-1} yr^{-1}	≤ 0.7	≤ 0.1	≤ 0.1	0.9	0.6	0.2	0.5	0.1	0.2
Beans (Phaseolus vulgaris spp.)	t homegarden^{-1} yr^{-1}	0.4-0.8	0.1- 0.4	0.1-0.2	0.7	0.4	0.2	1.5	0.2	0.8
Maize (Zea mays spp.)	t homegarden^{-1} yr^{-1}	0.3-1.0	0.1-0.5	0.1-0.2	1.0	0.6	0.2	0.6	0.1	0.5
Cassava (Manihot esculenta spp.)	t homegarden^{-1} yr^{-1}	n.d.	n.d.	n.d.	0.8	0.5	0.2	0.4	0.2	0.3
Groundnuts (Vigna subterranea)	t homegarden^{-1} yr^{-1}	n.d.	n.d.	n.d.	0.1	0.1	0.0	n. a.	n. a.	n. a.
Banana (Musa spp.)	t ha^{-1} yr^{-1} [II]	7.9-36	4.0-25.7	1.4-2.4	40.1	19.2	8.5	1.5	0.3	1.2
Coffee (Coffea canephora)	t ha^{-1} yr^{-1} [II]	≤ 0.5	≤ 0.2	≤ 0.1	0.1	0.1	0.3	0.2	0.1	0.1
Beans (Phaseolus vulgaris spp.)	t ha^{-1} yr^{-1} [II]	0.3-0.6	0.1-0.6	0.2-0.4	0.5	0.4	0.3	0.5	0.3	0.4
Maize (Zea mays spp.)	t ha^{-1} yr^{-1} [II]	0.2-0.7	0.1- 0.7	0.2-0.4	0.2	0.2	0.2	0.2	0.2	0.3
Cassava (Manihot esculenta spp.)	t ha^{-1} yr^{-1} [II]	n.d.	n.d.	n.d.	0.3	0.8	2.2	0.1	0.3	0.2
Groundnuts (Vigna subterranea)	t ha^{-1} yr^{-1} [II]	n.d.	n.d.	n.d.	0.0	0.1	0.0	1.5	n.a.	1.2
Livestock										
Improved cattle (Friesian, homegarden)	TLU [III]	2.0	0.6	0.0	2.7	*0.6*	*0.1*	0.2 [IV]	0.0 [IV]	0.1 [IV]
Indigenous cattle (grassland)	TLU [III]	≤ 26	< 10	0.0	n. d.	n. d.	n. d.	6.6 [IV]	0.0 [IV]	3.4 [IV]
Goats, sheep, pigs homegarden)	TLU [III]	≤ 2.0	< 1.2	≤ 0.3	1.8	1.4	0.7	1.1 [IV]	0.4 [IV]	0.8 [IV]
Chicken, rabbits (homegarden)	TLU [III]	≤ 1.0	≤ 0.4	≤ 0.2	0.5	0.3	0.2	0.1 [IV]	0.0 [IV]	0.0 [IV]
Bees (homegarden)	beehives	≤ 3	≤ 1	0.0	≤ 3	≤ 1	0.0	d. h. [IV]	d. h. [IV]	d. h. [IV]

Underlined figures are higher than those discussed in the FGD, figures in italics are lower. d. h. = we do not have this data. n. a. = not analysed. n. d. = not discussed. I Untrained farm households analysed by Reetsch et al. (2020a) with averaged values of the best performing none-vulnerable Group A.1, the most vulnerable Group C.1, and mean values of all households. II All crops grow in the same homegarden. The unit refers to multi-cropped land and not to monocultures. III Tropical livestock units (1 TLU = 250 kg) referring to smallholder farmers in Tanzania: 1 cow = 1.3 TLU; 1 goat, sheep, or pig = 0.2 TLU; 1 chicken or rabbit = 0.01 TLU (FAO, 2013; HarvestChoice, 2015). IV The data was partly published in Reetsch et al. (2020a) but taken from the same data set.

All households in Group A keep on average 5 tropical livestock units (TLU) in a permanent shelter (zero-grazing) in the homegardens and 26 TLU in the grassland (open-grazing). Farmers seek to control the number of livestock to avoid overgrazing. Farmers produce fodder and additionally buy nutrient-rich fodder. They provide medical care for their livestock.

Families are food secure due to constant food availability, diversity, and food access in dry seasons, and observe their health status to be generally healthy. All household members have three meals per day throughout the year. They have varied diets containing plantains, legumes, roots and tubers, fruits, vegetables, meat, milk, eggs, fish, honey, and purchased cooking oil. These households use mature crops for cooking and store food crops for three purposes: as food, for seeds, and for sale. They harvest rainwater for drinking and to irrigate the kitchen gardens. The harvested rainwater is stored in home-constructed (clay) tanks. Water intended for home use is at least boiled and often additionally filtered, or they buy drinking water in bottles.

Farm waste management

Corresponding to the relatively high biomass production, farmers have higher amounts of organic farm waste. Each kind of organic farm waste is used in a specific way, i.e., as mulch, fertiliser, fodder, or pesticide. Only human faeces are not used. Crop residues are used as mulch (*in situ* composting) or fodder during the dry season. Farmers separate inorganic from organic kitchen waste and dig waste pits near the kitchen house to ease its collection (pit composting). Some of the kitchen and food waste is fed to the livestock, and ground animal bones are used as a fodder supplement. Full waste pits are covered with earth, and rotten material is distributed over the homegardens. To produce organic fertiliser, all households in Group A have implemented trench composting, which was developed in cooperation with the farmers and the FFS. Each farm household in this group has dug one or two compost trenches parallel to the contour lines of the hills (Fig. 4-6 and Fig. 4-7).

Farmers dig 50 to 60 cm deep trenches at the end of the dry season at the latest (Fig. 4-8 and Fig. 4-9), add waste material (i.e., crop residues, kitchen waste, ashes, and livestock manure) in the following rainy season, and turn the rotting material over at least once a month. Full compost trenches are covered with earth, and rotten material is added to the soil after two to four months. To cover the soils at all times of the year, farmers harvest or buy grass. If livestock manure is not applied to the compost trenches, it is directly used in ring-hole composting around perennial crops.

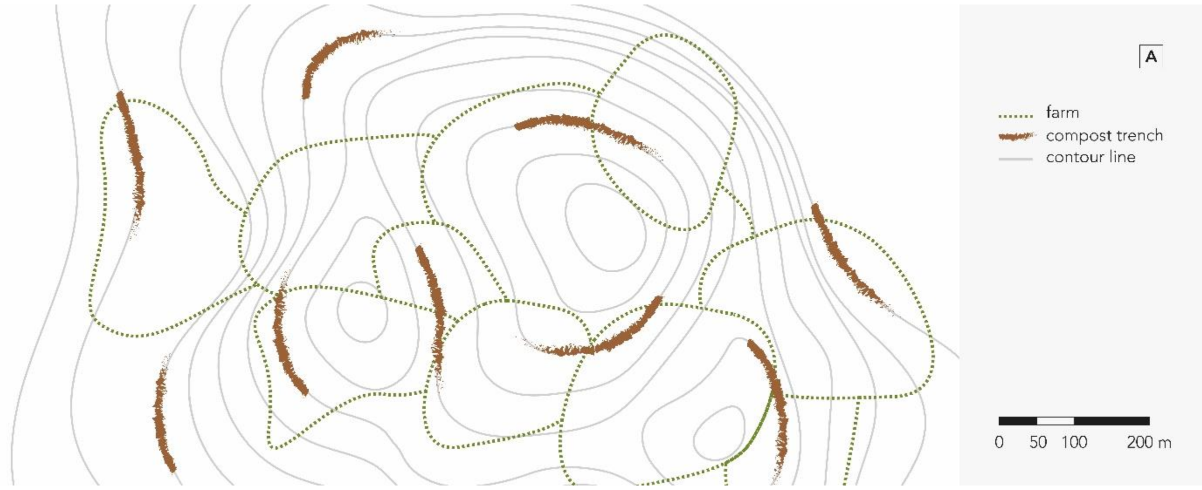

Fig. 4-6: Bird's eye view of the hilly terrain with contour lines (light green), farms (dotted dark green) and compost trenches (brown). (Design: Andreas Schulze)

Fig. 4-7: Sketch of compost trenches (brown) on a hill in banana-coffee-based farming systems. (Design: Andreas Schulze)

In general, farmers consider manure preparation as a high-cost practice, because it requires tools, equipment, and labour to collect and transport the manure. Farmers additionally buy livestock manure from households in Groups B and C.

None of the households applies mineral fertiliser nor chemical pesticides to the crops. To produce a preservative for stored beans, dried livestock manure is burnt, and the ash is used as the preservative. A mixture of cooking ash and human urine is used as an organic pesticide to minimise the spreading of banana diseases. To produce an organic pesticide, 1 kg of fresh material from the neem tree (*Azadirachta indica*) is ground, mixed with 5 litres of human urine, and stored in a covered container for 15 days. After 15 days, the mixture is diluted with fresh water (1:2) and combined with 250 mg of cooking ash and 30 mg of soap.

Fig. 4-8: Diagram showing the construction and filling of a compost trench to produce organic fertiliser using farm waste. (Design: Andreas Schulze)

The resulting mixture is spread around the roots of and applied to the bark of the banana plants. If necessary, the treatment is repeated after 7 to 10 days. Non-sanitised human urine is also used as an insecticide in the kitchen gardens.

Economy and education

Adult family members work 5 to 8 hours d^{-1} on the farm, and the families hire additional labour throughout the season. In addition to farm work, they work for small businesses or run their own, e.g., tailors' shops. Households in this group continue to prosper, have no financial problems, and generate income by selling mature crops, coffee cherries, meat, honey, firewood, fodder, timber, and animal manure. A portion of the bean harvest is sorted, treated with home-made storage preservative, and stored in home-made structures or storage bags. Farmers sell stored food crops for a higher price during times of food shortages and buy products from low-income farmers at a low price. The farmers can easily access the local and regional markets, e.g., in Kayanga, Mwanda, and Shinyanga. As harvest time approaches, traders visit the farmers, inspect the forthcoming harvest, and sign sale agreements in advance.

Thus, Group A farmers are informed about current prices and liaise frequently with the traders, knowing how to negotiate for a higher price. The farmers can wait for an increase in the price due to their ability to store food and to independently transport their products to the markets. The households also buy food or other goods at the local market when prices are low. Besides this, they sell coffee cherries to companies or cooperatives for a reasonable price, do not need to buy fodder during the dry season because they grow it themselves, and may buy new farmland.

Fig. 4-9: Compost trenches at the beginning of the rainy season. A. Empty compost trench dug along the contour lines or borders of a homegarden. B. Compost trench filled with crop residues and kitchen waste. In the background: the soil in the homegarden is additionally mulched with grass.

Concerning assets, these families own the farm, and live in modern houses with brick walls, electricity, and metal roofs. They have a TV, radio, and several mobile phones of which at least one is a smartphone. They possess good furniture, modified cooking stoves, solar power equipment with high capacity producing at least 1 kW electricity per day, farming tools, motorcycles, and bicycles. Some households also own a car and a biogas plant. They have improved pit latrines, which are about 4.5 m deep, and constructed of bricks, with permanent walls, a wooden or cement floor, a permanent door, and an aluminium roof.

In Group A, all children attend private primary and secondary schools and the family face no challenges in paying all school-related expenses. The parents also went to school. The children are among the best pupils and do well in their exams. The education level is high and remains high in successful families.

Gender-inclusive communication and decision-making

Households in Group A have changed traditional gender roles, have implemented a gender-inclusive and transparent communication culture and share responsibilities among all family members. Traditionally, women are responsible for annual crops and men for perennial crops. After the training, all family members are responsible for specific tasks and crops, regardless of their gender, e.g., both male and female household members now plant beans instead of women alone, as is the tradition. Clear information flow between all family members eases the management of the farm. Decisions on seeds, kinds of crops, time of harvesting, and the use of the harvest are jointly made after a family discussion, or at least between the parents. In contrast to the Nyambo-Haya tradition, in which assets, farmland and houses belong to the male head of the household, i.e., the oldest son, father or grandfather, most farm households in this group change ownership rights by including both genders in ownership.

4.3.2 Group B: Moderate successful farm households

Households in Group B are halfway to reaching the level of Group A, have started to integrate advanced fertility and pesticide management, are classified as middle-income earners (590 USD yr^{-1}), are able to cover their basic needs at almost any time of the year, seek to develop further, but have not enough food throughout the year.

Agricultural production and food security

Households in Group B implement the training on at least 0.1 ha and do not follow all instructions. Regarding diversity and yields, farmers produce less biomass and have smaller homegardens than those in Group A (Table 4-2). Group B households produce at least banana, coffee, maize, and beans, but plant fewer trees than households in Group A – up to five seedlings of traditional tree species in every rainy season. These households seldom have improved cattle and keep less indigenous cattle than Group A. For their livestock, they provide temporary shelter, e.g., goats are kept in temporary fences and chickens inside a shelter during the sowing and planting season, and outside in the dry season. Like households in Group A, most households have a kitchen garden for the cultivation of vegetables. A few households produce honey. Farmers in Group B also grow sweet potatoes, cassava, and peas as drought-tolerant crops, keep small livestock, and plant trees. However, they do not cultivate early-maturing crop varieties, plant fewer trees, and do not prevent soil drying through early mulching at the start of the rainy season.

In this group, each household member has two to three meals per day. Their diet is not as diverse as in Group A, as farmers seldom slaughter livestock, cannot afford to buy meat and cultivate fewer species of crops, fruits, and vegetables. Although farmers wait for the crops to mature before consumption and sale, they seldom store food for a long time. They store food for two purposes: as food and for seeds. Farmers also harvest and store rainwater as drinking water and to irrigate the kitchen garden. They do not filter the harvested rainwater water, but they do boil it, and store the water after boiling.

Farm waste management

Households in Group B have lower amounts of organic farm waste, and not all households have a compost trench. The compost trenches are shallower at < 50 cm deep. Crop residues are either used as compost material, fodder, or mulch. Most farmers leave the crop residues as mulch directly on the field (*in situ* composting). Farmers often apply the mulch too late, after the rainy season has started, when soil moisture has started to evaporate due to high temperatures. As in Group A, kitchen waste is separated into inorganic and organic fractions, and the latter is collected in waste pits. Organic kitchen waste and animal bones are ground and used as fodder, especially for chickens. These households do not have any food losses. As in Group A, livestock manure is used as fertiliser and pesticide, but farmers cannot afford to buy manure. A few households produce pesticides as Group A does, but often do not adequately apply this pesticide as recommended, e.g., missing ingredients. Human faeces are not used.

Economy and education

Households in this group have less income than Group A and struggle to fulfil all their needs. Farmers work 4 to 8 hours d^{-1} on the farm and only occasionally hire additional labour, and then only for a short time. They generate income by selling mature crops, but have a lower quantity and variety of crops than Group A households, or they work in (their own) small businesses. They hardly store crops for sale, instead selling mature crops directly after harvesting when the price is low. Farmers lack market information and market access and sell their crops at home on the traders' terms. However, farmers do sell coffee cherries to cooperatives for the same price as farmers in Group A.

The families live in traditional farmhouses, own a TV, radio, furniture, two mobile phones (no smartphone), farming tools, solar power equipment for electricity, bicycles, and sometimes modified cooking stoves and motorcycles. A few households possess a biogas plant. The walls of their pit latrines are built of brick, mud, and banana leaves. There is a mud floor and a roof made of aluminium, grass, or banana leaves. A wooden door, or at least a sheet of cloth functioning as a door, give some privacy.

In Group B, most children attend state primary and secondary schools. The families seek to fulfil all school expenses, e.g., buying school uniforms and paying fees. They desire to send their children to school, but it is not easy in practice due to limited finances, a lack of labour on the farm, or unsafe routes to school.

Gender-inclusive communication and decision-making

Gender roles are also changing in Group B, albeit to a lesser extent. Adult farmers (the parents) share collective responsibility for certain crops, e.g., beans and maize. Men are usually responsible for fetching water because distances can be long and the water heavy to transport. Decisions are made between the parents without involving the children. After discussion, the parents agree on the kinds of seeds, crops, time of harvesting and the use of the harvest. Like Group A, some households are changing their ownership habits.

4.3.3 Group C: Failing farm households

In contrast, farmers in Group C have failed to integrate any of the indicators completely. Belonging to the low-income earner (230 USD yr^{-1}), these households are often unable to cover their basic needs and are not developing towards the level of Group B.

Agricultural production and food security

Households in Group C fail to implement the training. They practise traditional farming and either focus on crop farming or livestock-keeping. The farms have the lowest crop diversity and produce the lowest yields (Table 4-2). Farmers often cultivate only one crop, e.g., either banana, maize, beans, or cassava, and plant no trees, have no kitchen gardens, produce no fodder or medicinal plants, and most households keep no livestock. They go into forests and woodland or cut trees belonging to the other two groups to get firewood and timber. If farmers keep livestock, they do not provide permanent shelter, i.e., goats are tied on a rope and chickens are range freely during the day and are kept inside the farmhouse at night.

Farmers in this group are the most vulnerable to food shortage, as they only have one meal per day – occasionally two They do not have access to food throughout the year and their diet is not varied, e.g., consuming unripe cooking bananas and beans once a week. They do not have vegetables, but they do eat small quantities of fruit. They store food only for seed production, but may need to consume the stored food before the new cropping season has started, thus leaving them with fewer seeds to sow. They neither harvest rainwater nor treat stream water before drinking it. They sometimes access water from public wells and carry it home on foot. Household members are often ill due to poor nutrition and dirty water. The trainers observed a relatively high rate of alcoholism in this group.

Households in Group C do not cultivate drought-tolerant or early-maturing crops. Farmers are forced to sell crops at an early stage of ripening in order to generate income quickly. Farmers prefer to plant banana plants instead of trees and think that the land is too small to grow both. These families suffer most from droughts and unpredictable rainfall patterns.

Farm waste management

Households in this group either do not have a compost trench or have only one small, shallow one, which is filled with crop residues and kitchen waste. They do not have any food waste and hardly produce or access any livestock manure. Some households collect livestock manure in the grassland and sell it. Farmers do not acknowledge the value of farm waste and fail to distribute rotten compost material to the soils. Usually, they leave the farm waste where it occurs or is produced without any collection or treatment. Free-range livestock eats plant-based farm waste wherever they find it. Farmers are often late with mulching, when soil drying has already started, and sell crop residues to households of Group A and B, or offer them for free. They do not separate organic from inorganic kitchen waste and throw unsorted kitchen waste into the homegardens. They do not produce pesticides, as ashes are associated with negative spirits. Human faeces are not used, while some of their human urine is directly added to the fields. Farmers do not produce organic pesticides.

Economy and education

The households in this group generate a low income through the sale of one immature crop at a low price. In the mornings, adults work 2 to 5 hours d^{-1} on their farm and never hire labour. Instead, in the afternoons, these farmers sell labour to Groups A and B. They lack market information and sell their crops at home. Before harvesting, farmers sign informal contracts with traders on the traders' terms. They find buyers as soon as their crops show any sign of maturity. Farmers fail to access the market due to financial constraints, timing, long distances, and lack of transport. They do not have off-farm income and live in traditional houses made of mud. They own one radio and a few pieces of furniture and farming tools. A few households own a mobile phone and solar power equipment for lighting. The pit latrines are built of plant material and have temporary doors or a sheet of cloth as a door, and lack privacy.

In contrast to Group A and B, most households in Group C cannot send their children to school because they cannot afford school fees, books, and uniforms; sending children to school without uniform discourages them. Financial and safety constraints are the highest in

Group C. Their children often roam the streets carrying out informal income generation activities, e.g., selling small items or begging.

Group C lack any market information and depend on the prices Group A and B determines. Families in Group C in particular are caught in a poverty trap due to the need to sell labour to Groups A and B to generate short-term income instead of working on their own farms. In the long run, dependencies on better-performing households and labour shortages reduce agricultural production by these groups and have a negative impact on their food security and access to education.

Gender-inclusive communication and decision-making

Farmers in Group C remain in traditional gender roles. Often one gender is responsible for a specific task, following the Nyambo-Haya tradition, e.g., women fetch water and grow beans while men cultivate banana. Decisions are not made collectively, and the households lack transparent information flow between all family members. Thus, they face conflicts in decision-making and farm management. Concerning ownership, farmers follow the Nyambo-Haya traditions and so the oldest male person owns the farm.

4.3.4 Remaining challenges and bottlenecks

Main challenges and bottlenecks for smallholder farmers in the study area remain in the management of farm waste, soil fertility, and energy. In general, all focus group members recommend installing UDDT toilets, and producing CaSa-compost as fertiliser (chapter 4.2.2). However, they emphasise the high cost of the UDDT and of the equipment for sanitising human urine and faeces, and the additional labour as the most significant challenges for the farmers. Although the CaSa-compost would be useful to all three groups of households, only a few farmers in Group A may be able to finance the UDDT, and none of the farmers from Groups B and C. Besides, if this is to be successful, communities need to be made aware of the benefits of using human excreta; it needs to be rendered acceptable to them. The trainers emphasise the need for measuring the status of soils in each field before adding any fertiliser to improve soil fertility management. Technical and economic obstacles to the introduction and use of UDDT and production of CaSa-compost as recommended by Krause *et al.* (2015, 2016) and Krause and Rotter (2017, 2018), and the health risks associated with the transmission of pathogens using livestock manure and human excreta (Kumwenda *et al.* 2017; Schönning *et al.* 2007; Winker *et al.* 2009) must be overcome in order to improve the safe production of organic fertiliser and to prevent wastewater leakage from pit latrines into water bodies. Further, salinisation of soils from human urine application needs to be considered (Andersson 2015).

The trainers of the FFS are unsure if the necessary organic materials would be accessible at all farms all year round. Thus, they have varying opinions on the likely level of implementation: either at the family level, or at a broader institutional level, e.g., schools, hospitals, churches, and prisons. To save labour, they suggested implementing the concept first in schools, where people are paid to empty pit latrines anyway.

In all groups of households, firewood and charcoal are the primary sources of energy. To reduce the amount of firewood and charcoal required, a limited number of households in Group A (below 10%) bought improved cooking stoves, e.g., solar cooking stoves and micro-gasifers, and some households built biogas plants (below 2%). The feedstocks for the biogas plants are crop residues and livestock manure. In Group B, households mainly use firewood for cooking, and a few families own improved cooking stoves and biogas plants, whereas in Group C, farmers only cook with firewood on 3-stone stoves.

4.4 Discussion

Compared to both fertile banana-coffee-based farming systems in the early 1960s (*cf.* Copeland Reining 1967; Katoke 1970) and today's untrained households in the same area (*cf.* Reetsch *et al.* 2020a), smallholder farming families who successfully implemented the SLM training have reached a higher level of agricultural productivity and multifunctionality, biodiversity, prosperity, and access to education. Multifunctionality of their homegardens is achieved by producing food, fodder, timber, and biofuel for consumption and sale, by providing soil- and water-related ecosystem services, and by adapting to climate change. Organic nutrient management plays a key role in increasing soil fertility and hence, agricultural production. Until the 1960s, fertile banana-coffee-based farming systems in the Kagera region consisted of four vegetation layers. Today, the vegetation density on successful restored farmland again reaches up to three vegetation layers (*cf.* Reetsch *et al.* 2020a). Hence, the SLM training of FFS contributes to the achievements of the SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), and SDG 15 (Life on Land – Target 15.3: Land Restoration) in rural areas where smallholder farmers are the backbone of the supply of (peri-)urban areas and the export economy.

Potential yields of highland banana (*Musa* spp.) are estimated to reach 70 to 100 t ha^{-1} under an optimum rainfall of 1,200 to 1,300 mm (IITA *et al.* 2019; Nyombi 2013; van Asten *et al.* 2011). When less rain is available, as in Karagwe and Kyerwa (982 ± 127 mm), the potential yield of *Musa* spp. decreases by about 10% per 100 mm decrease in precipitation (Nyombi 2013; van Asten *et al.* 2011). Accordingly, the potential yield of highland banana in the study is estimated to be between 30 to 50 t ha^{-1} yr^{-1}. The yield in the homegardens belonging to Group

A already reaches 11 to 50 t ha-1 yr^{-1}. Thus, banana production is about to reach its optimum in successful transformed farm households. In comparison, actual annual yields often lie below its potential in neighbouring regions and vary from 4.8 to 26 t ha^{-1} yr^{-1} in Uganda, 21 to 43 t ha^{-1} yr^{-1} in Burundi, and 25 to 53 t ha^{-1} yr^{-1} in Rwanda (IITA *et al.* 2019; Nyombi 2013; Wairegi and van Asten 2010).

Contrary to tradition (*cf.* Copeland Reining 1967; Reetsch *et al.* 2020a), rotted material from waste pits is distributed over the soils, and *in situ* composting of crop residues is less often practised by successful households. Instead, continuous surface covering mulching with grasses prevents soil erosion and improves soil moisture, which is necessary for optimal growth of highland bananas (*Musa* spp.). However, mulching might also lead to increases in nematode populations (Gaidashova *et al.* 2009; Wairegi and van Asten 2010). The new composting technique of compost trenches reduces soil erosion and increases water infiltration into deeper soil layers within the farm. Thus, water is more easily accessible for deeper root systems, especially for large trees, and promotes groundwater infiltration. Trees within the agroforestry system can thus survive more easily drought periods, which also occur more frequently during the rainy season. As a result, the farming system is better adapted to climate change that the region is experiencing.

Successful farms provide soil- and water-related ecosystem services, e.g., *provisional* (food and water), *regulating* (pollination through beekeeping, groundwater recharge through trench composting, pest and climate regulation, improving soil moisture by mulching fields with grass; frequent tree planting to increase shading and water storage capacities of soils and to minimise evaporation from soil surfaces), and *maintaining* (nutrient cycling and life cycle maintenance) (*cf.* Bouma 2014). Minimising erosion, improving carbon storage through humus accumulation, improving nutrient budgets and soil structure by reusing rotten material from composting as a soil conditioner are decisive to restore soil quality and mitigate soil degradation (*cf.* Lal 2015). Reetsch *et al.* (2020c) has shown that nutrient balances (NPK) in untrained households remain negative and turn positive in successful trained households.

Yields on all farms could be optimised if farmers consistently applied traditional and new composting techniques. However, as long as overgrazing of grassland by Group A and B farmers and overuse of woodland by Group C farmers is not reduced, environmental degradation outside the homegardens will not decrease. The nutrient balances of nitrogen (N), potassium (K) and phosphorus (P) in the homegardens depend on the nutrient inflows from the surrounding grass- and woodlands (Reetsch *et al.* 2020a). As a result, soil nutrient depletion cannot be overcome with organic farm management alone. We recommend that farmers in Group A and B consider the integration of controlled application of mineral fertiliser to overcome the extraction of nutrients by harvest (*cf.* Vanlauwe and Giller, 2006). Organic waste management (composting) and mineral fertiliser can create added benefit to soils and plants. For instance, organic matter on soils prevent soil drying in dryer seasons of the year while the application of mineral fertiliser provides nutrients for crops (Vanlauwe 2015). Besides, higher quantities of organic materials are produced. The accumulation of soil organic matter and humus promotes nutrient storage in soils. However, caution is required here. If mineral fertilisers are not applied correctly in quantity amount, time and place, they can increase environmental degradation, e.g., through groundwater pollution.

The SLM training is cross-sectorally linked to the Water-Energy-Food (WEF) Nexus and the Water-Soil-Waste (WSW) Nexus (Hettiarachchi and Reza Ardakanian 2016; Hülsmann and Reza Ardakanian 2018; Rasul and Sharma 2016). However, the 'water' component in both nexi should be further emphasised by enhancing water harvesting for domestic use and irrigation, providing drinking water treatment with advanced filtration techniques, and preventing wastewater leakage from pit latrines into underlying groundwater aquifers and adjacent surface water bodies, rivers and lakes, e.g., the Kagera River and Lake Victoria, especially after heavy rainfall (Masso *et al.* 2017; Reddy *et al.* 2018). For increased rainwater harvesting, local water-related infrastructure is needed to catch heavy rainfall in a short time. Rainwater storage capacities need to be equal to the water demand during the dry seasons, e.g., to irrigate kitchen gardens, and to compensate for rain shortages in the rainy season. We suggest additionally basing the SLM training on the concept of agroecology to improve food security and water harvesting, as described by Gliessman (2015), who defined agroecology as *'the science of applying ecological concepts and principles to the design and management of sustainable food systems'*, and applied by Weckenbrock and Alabaster (2014) to improve wastewater irrigation in agriculture. We further suggest integrating the action of FFSs into long-term agricultural and food security strategies to transform unsustainable food production systems into sustainable, multifunctional systems as called for in the Paris Agreement and demanded by the IIASA and SDSN (2019). Locally adapted concepts of agroforestry that involve ecological, economic, social, and cultural aspects can play a crucial role in long-term strategies to provide sustainable food systems and for climate regulation as suggested by Gliessman (2015). Thus, farmers around the world could become promoters of clean and environmentally friendly production. In order to solve the complex and pernicious environmental problems, we need sophisticated, time-saving methods that are inter- and transdisciplinary (Bouma and Montanarella 2016; Nyanga 2012), and the application of 'mixed methods' in the field of agricultural and land-use change research is one solution (Cheong *et al.* 2012). Therefore, we see an opportunity for the application of 'mixed methods' in the science-policy interface, where diverse and holistic, interdisciplinary, transdisciplinary, scientifically sound solutions must be developed in a stakeholder-oriented atmosphere, often within a short time frame and with limited financial resources.

In our previous research, we also highlighted that untrained, female-led households are most vulnerable to food shortages and lack basic socio-economic needs (Reetsch *et al.* 2020a). Female farmers now run approximately one-third of all trained households, whereas only 16% of the best-performing 'untrained' households were female-led (*ibid*.). As a core element for success, gender-inclusive communication and decision-making processes facilitate farm management and increase production. Burdens are distributed across all family members' shoulders instead of separating tasks by gender as is the Nyambo-Haya tradition (*cf.* Copeland Reining 1967). Besides, households in Groups B and C are more likely to suffer the consequences of HIV/AIDS than families in Group A because they can neither afford to buy all the medicine needed, nor to balance the loss of labour (Oramasionwu *et al.* 2011; Reetsch *et al.* 2020a). Changes in sexual behaviour and a reduction in polygynous marriages have led to a decline in HIV/AIDS in Uganda (Green *et al.* 2006), and could become part of the farmers' training in the Kagera region. At the community level, informal institutions need to be further understood in order to address and avoid land-use conflicts, e.g., conflicts over firewood and the risk of overgrazing in common grassland, as Yami *et al.* (2011) described for Ethiopia. Further, we assume that farm nutrient management has lost importance in households where hunger and disease are prevalent.

However, not all challenges have been overcome, and the following bottlenecks still exist. The full potential of using organic farm waste in nutrient cycling has still not been exhausted, as human excreta are not used. Here, soil nutrient balances need to be calculated to investigate the potential of human excreta to fill nutrient gaps. Therefore, the next step should be an analysis of biochemical and physical soil properties, as well as biomass and farm waste sampling. This would allow us to quantify and investigate soil nutrient deficiency, along with the effects of current practices that replace nutrients with organic fertiliser, as well as the potential impact of future organic fertiliser using human excreta, and of mineral fertiliser application. Also, further study is needed of the positive and negative effects of open grazing vs. zero-grazing regarding nutrient cycling, labour, and animal welfare in order to find an appropriate balance of how to use all land types sustainably, i.e., to minimise overgrazing and to optimise nutrient uptake from livestock manure and urine by plants.

In summary, the SLM training could be further improved via the following measures:

- Making full use of organic farm waste:
    a) reuse of human urine and faeces for soil fertilisation (Andersson 2015; Krause *et al.* 2015, 2016);

b) integration of biochar as a soil conditioner to ensure a longer effect of organic fertilisation and the development of permanent humus, which is responsible for the improvement of physical soil properties, e.g., water storage and aggregate stability (Verheijen *et al.* 2014; Verheijen *et al.* 2017);
c) using residues from coffee cherries as biogas feedstock or for composting (Battista *et al.* 2016; Ruben *et al.* 2018); and
d) using water hyacinth (*Eichhhouseholdsornia crassipes*) as mulch and feedstock for biogas production in areas near the Kagera River and Lake Victoria (Güereña *et al.* 2015; Gunnarsson and Petersen 2007; Indulekha and Thomas 2018; Priya *et al.* 2018); Priya *et al.*, 2018);

- Integrating leguminous plants and covering crops to increase soil fertility (Baijukya *et al.* 2005a; Baijukya *et al.* 2005b, 2006; Keino *et al.* 2015; Vandamme *et al.* 2014);
- Actively integrating soil organic carbon management (Kirsten *et al.* 2019; Nandwa 2001) and carbon sequestration (Adhikari and Hartemink 2016; Bouma 2014);
- Considering mineral fertiliser (Vanlauwe and Giller 2006);
- Promoting water harvesting; innovative, multipurpose trees, e.g., shea tree (*Vitellaria paradoxa*), ackee (*Blighia sapida*), acacia (*Acacia* spp.) (Ekué *et al.* 2010; Elias and Carney 2007; Koutika and Richardson 2019; Kull *et al.* 2011);
- Further reducing firewood demand and promoting alternatives, e.g., solar power electricity, solar cooking stoves and biogas plants, which should prevent land-use conflicts over firewood;
- Promoting medicinal plants, e.g., from traditional Haya medicine (Chhabra and Mahunnah 1994; Moshi *et al.* 2009);
- Preventive measures against malaria and HIV infection (Dunlap *et al.* 2014; Newman *et al.* 2006; Siegler *et al.* 2012; Starmann *et al.* 2018; Wort *et al.* 2006); and
- Access to medical care and education.

4.5 Conclusions and recommendations

In the area under investigation, training in SLM practices considerably enhance agricultural production in previously degraded banana-coffee-based farming systems and thus, food security of smallholder farming families. Successful implemented knowledge on soil and farm nutrient management, the selection of suitable crop species, afforestation, as well as improved work allocation and time management, agricultural accounting, and gender-inclusive communication and decision-making leads towards biodiverse, multifunctional agroforestry systems. The degradation of soil and vegetation resources decreases in transforming farms. However, on non-transforming farms it continues. In addition, successful farmers can meet most current challenges, i.e., limited land size, labour shortages, and climate change, through agricultural intensification and adaptation to climate change. However, the full potential of multifunctionality in agroforestry has yet to be unlocked. On small farms, the SLM training of the FFS provides a pathway out of poverty for successful households, but households who fail to implement the training need further support and incentives. Transforming farmers become food secure, whereas non-transforming farmers remain food insecure.

New research questions have emerged. It is still unclear, why some farm households successfully implement the SLM training and others not. It might be of higher interest to identify underlying causes which explain why farmers in Group B and C fail partially or completely. We assume underlying social, psychological, and economic reasons for this. For example, family size and support outside the core family, affection through illness, alcoholism, coping with stressful long-term situations, and financial starting situation. One observation made in the field is that when hunger and disease prevail, farm management loses priority. In conclusion, further investigations need to be carried out, focussing on the socio-economic conditions and constraints, particularly of unsuccessful farming families.

We propose to optimise the SLM training in promoting the reuse of human urine and faeces for soil fertilisation, integration of biochar, using residues from coffee cherries as biogas feedstock or for composting, using water hyacinth (*Eichhornia crassipes*) as mulch and feedstock for biogas production in areas near the Kagera River and Lake Victoria, promoting leguminous plants and covering, integrating soil organic carbon management, considering mineral fertiliser, promoting water harvesting, reducing firewood demand and promoting alternatives, promoting medicinal plants, promoting preventive measures against malaria and HIV infection and access to medical care.

Future research should also focus on the following: (i) analysis of the farm nutrient balance for each farm household group, (ii) measurement of soil parameters, (iii) analysis of the carbon sequestration potential of restored farms compared to degraded farms, (iv) psychological and socio-economic analysis and deeper understanding of why some households (partly) fail to implement the training.

4.6 Acknowledgements

We acknowledge the Heinrich Böll Foundation and the United Nations University for funding, Abel Leonard Mtembejji and Joana Lapao Rocha for their incredible commitment during the fieldwork and data preparation, and the local non-profit organisation MAVUNO Project in Tanzania, in particular Charles Bahiti, Adam Bitakwate and Ibrahim Bamuhiga, for their close and sincere cooperation, without whom the data collection would not have been possible; we appreciate the constant support, honest communication, and fun we had during the fieldwork. We hope that our research will help to support the MAVUNO Project to further improve its training and to serve as a best practice example for other FFSs, non-profit organisations and governmental initiatives. We also thank Ariane Krause for connecting us with the MAVUNO Project and for inspiring our research. We warmly thank Sekela Twisa and Mohamed Mwabumba for hosting us in Dar es Salaam. Lastly, we gratefully acknowledge the United Nations University and the Heinrich Böll Foundation for funding, Claudia Matthias, Atiqah Fairuz Salleh, and Andreas Schulze for designing the figures in this paper, and Helen Grützner for her constant support and guidance in the editorial aspects of the paper.

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5 Optimised nutrient management

This chapter has been published as a journal article.

Reetsch, A., Schwärzel, K., Dornack, C., Stephene, S., and Feger, K.-H. **2020b**. "Optimising Nutrient Cycles to Improve Food Security in Smallholder Farming Families—A Case Study from Banana-Coffee-Based Farming in the Kagera Region, NW Tanzania." *Sustainability* 12, 9105, https://doi.org/10.3390/su12219105.

Sustainability

Optimising nutrient cycles to improve food security in smallholder farming families— A case study from banana-coffee-based farming in the Kagera region, NW Tanzania

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Received: 1 May 2020; Accepted: 15 September 2020; Published: 2 November 2020

Abstract

In East Africa, soil nutrient depletion and low yields jeopardise the food security of smallholder farming families and exacerbate poverty. The main reasons for the depletion of soil nutrients are overuse due to population growth, limited land, and increasing uncertainty in agricultural production caused by climate change. This study aims to analyse and optimise nutrient flows and stocks in the homegardens of smallholder banana-coffee-based farming systems in the Kagera region in NW Tanzania. The plant nutrients nitrogen (N), phosphorus (P), and potassium (K) in plant-based biomass and organic farm waste are under investigation. We used data from a farm household survey (150 households) and from focus group discussions with 22 trainers who had been training about 750 farm households in sustainable land management (SLM) at a local farmer field school. In total, we identified six farm household types and calculated a nutrient balance (NB) for the homegardens of each household type. The NB was calculated for the following five management scenarios: S0: business as usual; S1: the use of 80% of the available human urine; S2: the incorporation of 0.5 t yr^{-1} of the herbaceous legume species *Crotalaria grahamiana* into the soil; S3: the production of 5 m^3 yr^{-1} CaSa-compost (human excreta and biochar) and its application on 600 m^2 land; and S4: a combination of S1, S2, and S3. The results show that the NB varies considerably depending on whether farmers have implemented the SLM training, apply nutrient-preserving manure collection and storage methods, and purchase fodder (imported nutrients), or whether they do not collect manure, or do not purchase fodder. Trained farm households are more likely to have a positive NB than untrained households because they have already improved the nutrient management of their farms through the successful implementation of SLM practices. Untrained households would improve the NB in their homegardens under all management scenarios. However, the NB depends on labour-intensive manure collection and compost production, labour shortages, prolonged dry seasons, and socio-economic imbalances. As long as these constraints remain, nutrient deficiencies will not be overcome with mineral fertilisers alone, because soils have to be further enriched with organic matter first. In this paper, we also emphasise the importance of the system boundary, because only a complete NB can give an estimate of actual nutrient removal and the resulting nutrient demand (including removals by fodder and trees). Further improvements in the SLM training may be achieved by i) measuring the current nutrient status of soils, (ii) analysing the need for the coexistence of free-range livestock on the grassland and zero-grazing in trained households, and (iii) conducting an in-depth analysis of the socio-economic differences between successful and unsuccessful households. In conclusion, if smallholder farmers were to integrate further improved SLM training and optimised nutrient management (S1 to S4), we assume that the NB would turn positive. Last but not least, the SLM training by the farmer field school may serve as a best-practice example for training and policy recommendations made by government institutions.

Keywords

Sustainable land management; soil fertility management; farm waste management; agroforestry; nutrient balances; human urine; legume; biochar; CaSa-compost; food security

5.1 Introduction

In Sub-Saharan Africa (SSA), rapid population growth has increased demand for food, water, and energy, while limited land, water scarcity, environmental and soil degradation, and growing regional vulnerability to climate change hamper agricultural intensification [1–4] Yield gaps and food imports remain high in many African agricultural systems. Although total cereal production has increased over the last four decades, production per hectare remains highly variable, and food production is not keeping pace with population growth [5–6]. Since most farmers in SSA are subsistence smallholder farmers, poor yields directly drive such farmers into poverty [7–9].

Yields are stagnating or collapsing due to poor soil fertility, poor nutrient and water management, low organic and mineral inputs, labour shortages, and progressive climate change (unpredictable rainy seasons, intermittent rain, and prolonged droughts) [10–14]. As a result of these constraints, the soil nutrient balance (NB) in small-scale farming systems is often negative because nutrient removals are often higher than nutrient inputs [15–18]. In previous studies, the NB in sub-humid mountainous regions in East Africa varied between -77 and 17 kg N, -8 and 7 kg P, -57 and 12 kg K ha^{-1} yr^{-1} (on *Andosols*, *Ferralsols,* and *Plinthosols*), with positive values on farms with access to cattle manure and biomass imports from the surrounding grass- and woodland [19–21].

Soil nutrient analyses and nutrient management were based on the principles of the circular economy (CE) long before the conceptual framework of the CE was named and written down by Pearce and Turner in 1990 [19] (e.g., in 1946 and 1961, in the studies on the relationship between crop yield and soil nutrient status [20,21], and in 1977, in the study on nutrient intensity (concentration) [22]): *"The central theme of the CE concept is the valuation of materials within a closed-loop system with the aim to allow for natural resource use while reducing pollution or avoiding resource constraints and sustaining economic growth"* [19]. In recent years, the concept of the CE has become much more attractive, as overconsuming throwaway societies in industrialised countries have increasingly developed the desire or the need to transform into zero-waste societies. However, smallholder farming families in East Africa are hardly a affected by overconsumption, and seek to use and reuse materials they produce on their farms, which they rarely call "waste". Using organic farm waste as fertiliser is still the most prominent example of the applied CE in East African agriculture. Another example of the reuse of waste in agriculture is the use of old plastic water bottles for drip irrigation. Farmers have become informal experts in composting and the production of organic fertiliser. As the authors in [23] note, *"farmers possess intuitive knowledge of the decomposition and nutrient mineralisation of the readily available organic resources"*.

In this context, we investigated in previous studies how 150 smallholder farming families used organic farm waste and how another 750 farm households were trained in sustainable land management (SLM) by a self-organised farmer field school [24,25]. Both groups of farmers practise small-scale, organic agriculture to produce plantain (*Musa* spp.) as their main staple crop, coffee (*Coffea canephora var. robusta*) as their principal cash crop, and common beans (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.) as additional food crops in rainfed banana-coffee-based farming systems in the mountainous Kagera region in NW Tanzania [24,26,27]. They rarely have access to synthetic fertiliser (under 2% of the households in the area). In the past, the composting of organic farm waste, such as livestock manure, crop residues, litter, kitchen and food waste, and human urine, was of crucial importance for maintaining the soil fertility of homegardens and is still an important practice today [24,28–30]. Since the 1950s, the region has experienced rapid population growth, partially due to refugee immigration. Previously fertile soils and densely grown, multi-layered homegardens have been degraded into single-layered vegetation with just a few crops, such as bananas and beans, on poor soils [24,25,31–33].

This previous research led us to the question of whether nutrient cycles could be closed to increase soil fertility and crop productivity and, if so, under what conditions. Thus, here we ask the following research questions: (A) Are the nutrient balances of trained households more positive than those of untrained households? (B) Can nutrient cycles be closed through composting? (C) Under what scenarios could soil nutrient balances be optimised? (D) What other ecological and socio-economic conditions need to be met to close nutrient cycles at the farm level? To answer these questions, we used material flow analysis (MFA) to calculate the NB of nitrogen (N), phosphorus (P), and potassium (K) for each household group in five scenarios. In this paper, we give background information on the study area and the data sets used, describe the variables applied in the MFA in detail, and introduce the scenarios (chapter 5.2.2). Values for the variables can be found in the chapter 5.6. We have illustrated the main results in a Sankey diagram (chapter 5.3) and discuss the methodology and the results in chapter 5.4.1. Our conclusions also involve recommendations for science and policy development.

5.2 Materials and methods

5.2.1 Study area

The study area covers the Kyerwa and Karagwe districts in the Kagera region in NW Tanzania between 1.0°S, 30.4 °E, 1,200 m a.s.l and 2.1°S, 31.4 °E, 1,650 m asl (Fig. 5-1).

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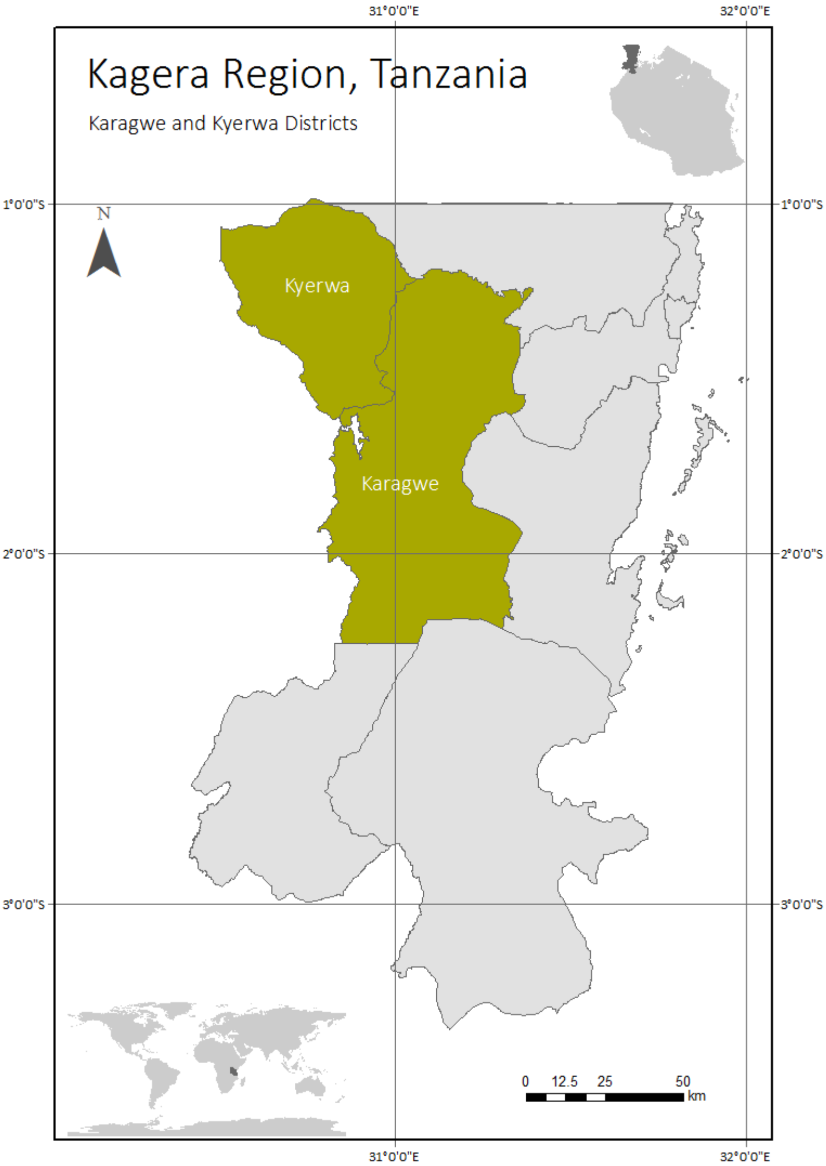

Fig. 5-1: Map of the study area showing the Karagwe and Kyerwa districts of the Kagera region in NW Tanzania [24].

The region is characterised by a bimodal rain pattern, with annual precipitation of 716 to 1,286 mm (mean 982 ± 127 mm) in Kayanga, and moderate temperatures, with minimum mean temperatures between 11.6°C and 16.2°C and maximum between 24.6°C and 28.3°C [25,34,35]. Most of the rain falls in two rainy seasons, the Masika rainy season from March to May, and the Vuli rainy season from October to January. Soils in the study area are variously classified as *Andosols*, *Ferralsols*, *Leptosols*, *Acrisols*, *Cambisols*, and *Phaeozems*; in river terraces as *Fluvisols*, *Gleysols*, and *Planosols*; and in swamps as *Histosols*, with *Andosols* and *Ferralsols* being the most important soil types for agricultural production (up to 90%) [25,34].

5.2.2 Data

In this paper, we combine two data sets from our previous research. The first data set is quantitative and is taken from a survey of 150 smallholder farm households [24]. The second data set is qualitative and is taken from five focus group discussions with 22 trainers from the local farmer field school: the MAVUNO Project [25].

Background information on the data

In our previous research, we built farm household typologies for each of the two data sets. Each data set resulted in three household groups as follows: A_U) non-vulnerable to food insecurity, untrained; B_U) vulnerable, untrained; C_U) most vulnerable, untrained; A_T) non-vulnerable, trained; B_T) vulnerable, trained; and C_T) most vulnerable, trained. Groups A_U to C_U emerged from the survey data [24] and groups A_T to C_T from the focus group discussions [25]. The main household and production data of all groups are presented in Table 5-1

The findings in [24] revealed that (a) farm nutrient management in untrained households (groups A_U, B_U, and C_U) is based on the traditional practices of *in situ*, pit, and ring-hole composting of crop residues, and (if available) kitchen and food waste and livestock manure; however, (b) half of the livestock manure is not collected and thus remains unused; (c) the nutrients in coffee hulls are exported in their entirety; (d) 30% of the untrained households use human urine as an organic fertiliser and pesticide; (e) none use human faeces; and (f) the remaining inorganic ash from cooking above three-stone fires is rarely used in farm waste management due to negative spiritual beliefs.

In comparison, trained households (groups A_T, B_T, and C_T) also apply *in situ*, pit, and ring-hole composting to produce organic fertiliser and additionally employ: (a) trench composting along contour lines to minimise soil erosion from runoff and to increase water infiltration along the trenches; (b) zero-grazing in homegardens to facilitate manure collection and livestock monitoring; (c) the mulching of bare soils with grass throughout the year; (d) the cultivation of drought-tolerant crop species to meet changing rain patterns; (e) the frequent planting of indigenous tree species to increase biodiversity, provide shade for underlying crops, and compensate for the deforestation of nearby woodlands and forests; and (f) gender-inclusive communication and decision-making, and gender-balanced labour division [25].

However, in both cases, the crop yields remained below the potentially attainable yields. Not all farm households have been equally successful in implementing their training, and some families remain trapped in a weak socio-economic position [24,25].

Table 5-1: Characteristics of smallholder farm household groups. Untrained households (groups A_U, B_U, C_U) were surveyed in 2017 and grouped within a multivariate statistical analysis [24]. Mean values of the quantitative survey data are presented here. Trained households (groups A_T, B_T, C_T) were trained in sustainable land management (SLM) [25]. Qualitative data from focus group discussions with the trainers who trained the households are also presented here.

Household characteristics		**Untrained household** [I]				**Trained farm households** [II]		
	Unit	A_U	B_U	C_U	*Mean*	A_T	B_T	C_T
	household group^{-1}	*58*	*52*	*44*		*296*	*262*	*198*
Homegarden size								
Homegarden	ha (average)	2.8	1.8	0.6	1.8	0.6–2.8 (1.4)	0.4–1.0 (0.7)	0.2–0.8 (0.5)
Transformed homegarden	ha (average)	0.0	0.0	0.0	0.0	0.4–0.8 (0.6)	0.1–0.4 (0.2)	≤ 0.1
Household characteristics								
Household size	p household^{-1}	10.2	9.7	5.7	8.5	5.3	5.1	5.1
Female-headed	% of households	16	35	43	31	30	29	33
Labour	hours adult^{-1} d^{-1}	5.6	5.0	3.6	n.a.	7.6	6.7	5.1
Available food [III]	months yr^{-1}	6.6	3.2	1.7	4.2	n.a.	n.a.	n.a.
Meals	meals day^{-1}	n.a.	n.a.	n.a.	n.a.	3.0	2.2	1.7
Crop yields								
Banana (Musa spp.)	t homegarden^{-1} yr^{-1}	4.2	1.8	0.2	2.1	11–57	2.8–18	0.7–1.2
Coffee (Coffea canephora)	t homegarden^{-1} yr^{-1}	0.5	0.1	0.1	0.2	≤ 0.7	≤ 0.1	≤ 0.1
Beans (Phaseolus vulgaris spp.)	t homegarden^{-1} yr^{-1}	1.5	0.7	0.2	0.8	0.4–0.8	0.1–0.4	0.1–0.2
Maize (Zea mays spp.)	t homegarden^{-1} yr^{-1}	0.6	0.7	0.1	0.5	0.3–1.0	0.1–0.5	0.1–0.2
Cassava (Manihot esculenta spp.)	t homegarden^{-1} yr^{-1}	0.4	0.4	0.2	0.3	0.8	0.5	0.2
Banana (Musa spp.)	t ha^{-1} yr^{-1} [IV]	1.5	1.0	0.3	1.2	7.9–36	4.0 - 25.7	1.4 - 2.4
Coffee (Coffea canephora)	t ha^{-1} yr^{-1} [IV]	0.2	0.1	0.1	0.1	≤ 0.5	≤ 0.2	≤ 0.1
Beans (Phaseolus vulgaris spp.)	t ha^{-1} yr^{-1} [IV]	0.5	0.4	0.3	0.4	0.3–0.6	0.1–0.6	0.2–0.4
Maize (Zea mays spp.)	t ha^{-1} yr^{-1} [IV]	0.2	0.4	0.2	0.3	0.2–0.7	0.1–0.7	0.2–0.4
Cassava (Manihot esculenta spp.)	t ha^{-1} yr^{-1} [IV]	0.1	0.2	0.3	0.2	0.6	0.4	0.1
Livestock								
Improved cattle (Friesian) (homegarden)	TLU [V]	0.2[VI]	0.3[VI]	0.0[VI]	0.1[VI]	2.0	0.6	0.0
Indigenous cattle (grassland)	TLU	6.6[VI]	3.1[VI]	0.0[VI]	3.4[VI]	≤ 26	< 10	0.0
Goats, sheep, pigs (homegarden)	TLU	1.1[VI]	0.9[VI]	0.4[VI]	0.8[VI]	≤ 2.0	< 1.2	≤ 0.3
Chickens, rabbits (homegarden)	TLU	0.1[VI]	0.0[VI]	0.0[VI]	0.0[VI]	≤ 1.0	≤ 0.4	≤ 0.2
Bees (homegarden)	beehives	0.0[VI]	0.0[VI]	0.0[VI]	0.0[VI]	≤ 3	≤ 1	0.0

A, B and C = household group identity, U = untrained, T = trained, and n. a. = not analysed.

[I] *Untrained farm household groups analysed in [24] from household data [36,37], with the averaged values of each group and mean values of all groups.*

[II] *Trained farm households analysed in [25] from focus group discussions and interviews with SLM trainers.*

[III] *Number of months in one year in which the household has enough food and is not starving or hungry as self-assessed by the households.*

[IV] *All crops grow in the same homegarden. The unit refers to multi-cropped land and not to monocultures.*

[V] *Tropical livestock units (1 TLU = 257 kg) referring to the smallholder farmers in Tanzania; 1 cow = 1.3 TLU; 1 goat, sheep, or pig = 0.2 TLU; 1 chicken or rabbit = 0.01 TLU [38].*

[VI] *The data were not published in [24] but taken from the same data set [36,37].*

In this analysis, the following input, output, and stock variables were considered:

INPUT

Atmospheric deposition (IN1)
Inputs by plants and trees (IN2)
- *Litterfall (IN2a)*
- *Deep capture (IN2b)*
- *Biological fixation (IN2c)*

Organic fertiliser (IN3)
- *Crop residues (IN3a)*
- *Kitchen and food waste (IN3b)*
- *Cooking ash (IN3c)*
- *Livestock manure and urine (IN3d)*
- *Human excreta (IN3e)*

OUTPUT

Harvested crops (OUT1)
- *Perennial crops (OUT1a)*
- *Annual crops (OUT1b)*

Fodder (OUT2)
Wood (OUT3)
Sold crop residues (OUT5)
Leaching from soil (OUT6)
Leaching from pit latrines (OUT7)
River discharge (OUT8)
Gaseous losses (OUT9)

STOCK

Human body (STOCK1)
Animal body (STOCK2)
Pit latrine (STOCK3)
Soil (STOCK4)

Input variables lead to an inflow of N, P, and K into the farm system, and output variables to an outflow out of the farm system. Stocks are elements of the farm system where N, P, K are saved for a certain time, e.g., human excreta in pit latrines. The boundaries of farming systems are key in calculating and interpreting the NB. Depending on the system boundaries that are defined, and the flows and stocks considered, the NB may vary between positive, neutral, and negative on the same piece of land [17,18].

The analysis followed a scheme of biomass and waste dynamics (Fig. 5-2) incorporating seven sub-systems: soil, farm, food production, energy, food processing, sanitation, and composting. The system boundaries are set around these sub-systems.

Variables

We collected values for the variables from a systematic literature review after [47] on the Web of Science by using the search string “TITLE: (nutrient balance) AND TOPIC: (Africa)”. The variables are described and calculated as follows.

Deposition (IN1)

In dense montane tropical forest systems, the wet deposition of total dissolved nitrogen (TDN) is about 21.2 kg N ha^{-1} yr^{-1} on *Ferralsol* and *Acrisol* in the Congo basin, comprising $NH4^+$, $NO3^-$, and dissolved organic nitrogen (DON) of 9.6, 5.8, and 5.8 kg N ha^{-1} yr^{-1}, respectively [48]. These values are considered the maximum values for IN1a, whereas the estimated wet deposition from the rain samples was about 1.8 kg N ha^{-1} yr^{-1} in the same study area (Karagwe-Ankolean) 20 years ago [25,49].

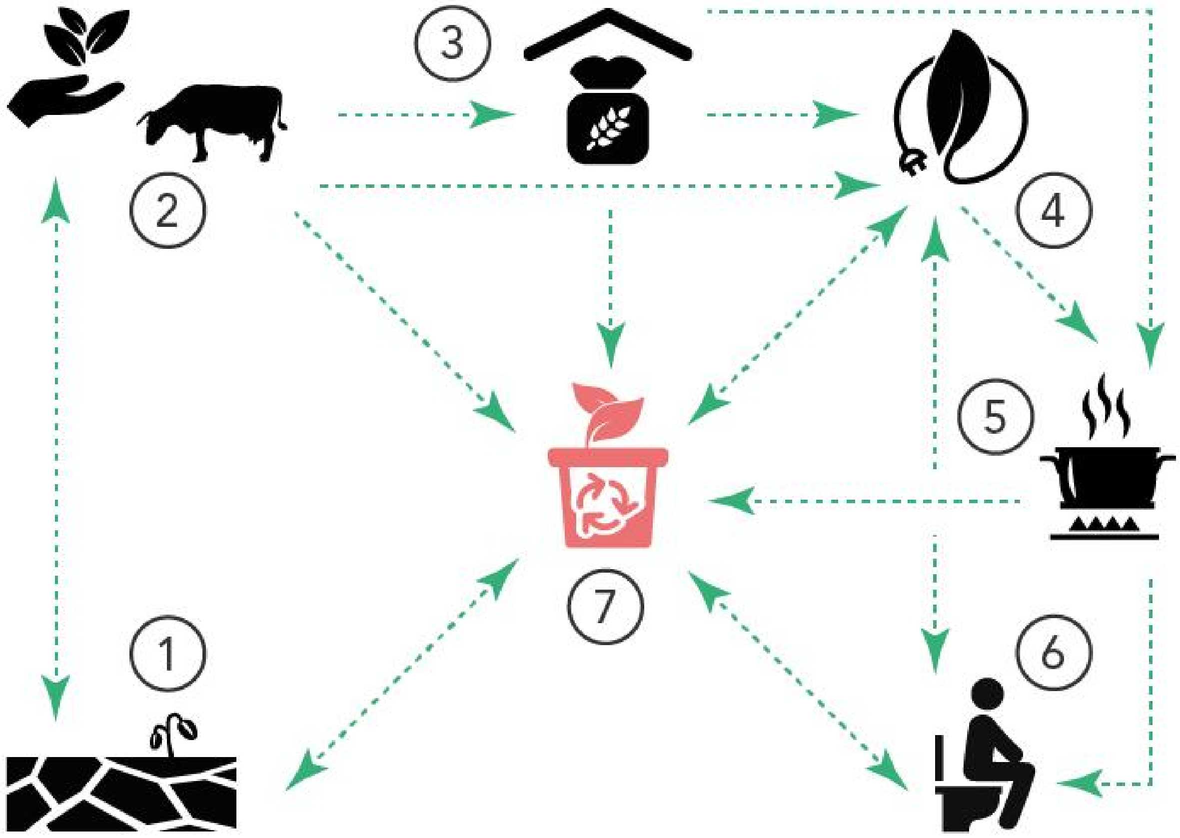

Fig. 5-2: Biomass and waste dynamics and the mass fluxes of nutrients and energy in multifunctional land-use systems in smallholder farming systems in the sub-humid highlands of East Africa. Labelling as follows: 1: the soil sub-system, 2: plant and animal production as a sub-system, 3: harvest and storage of food, 4: bioenergy production, 5: food processing, 6: sanitation, and 7: the compost sub-system. (Design: Claudia Matthias).

In [50] atmospheric deposition (wet and dry) was estimated according to [46] by using the following equations (with p for annual rainfall in mm yr^{-1}):

$$IN1_{a_N} = 0.14 \times p^{\frac{1}{2}} (1)$$

$$IN1_{a_P} = 0.023 \times p^{\frac{1}{2}} (2)$$

$$IN1_{a_K} = 0.092 \times p^{\frac{1}{2}} (3)$$

We applied these equations in this paper, and found that atmospheric deposition reaches 4.4 kg N, 0.7 kg P, and 2,9 kg K ha^{-1} yr^{-1}, with a mean annual rainfall of 982 mm.

Above-ground and below-ground inputs by plants and trees (IN2)

To determine the above-ground and below-ground inputs by plants, we have summarised the litterfall (IN2a), deep capture (IN2b), and biological fixation (IN2c).

Litterfall (IN2a) and deep capture (IN2b)

We found litterfall data for a mixed crop-livestock-forest system in Cameroon with a bimodal tropical rainfall regime and a multitude of crops, such as cacao and plantain, as well as trees with food and medicinal value and timber tree species [50] The annual litter fall was measured to be 5 t ha^{-1} yr^{-1}, with nutrient inputs of 66 kg N, 5.2 kg P, and 26 kg K ha^{-1} year^{-1} and a corresponding deep capture of 16 kg N, 1.4 kg P, and 6.6 kg K ha^{-1} yr^{-1} [50]. The authors in [50] assumed that 75% of the nutrients in the litter were recycled in the root zone and that 25% were deep-captured from below the root zone, as most trees on acidic soils (pH$_{KCl}$ 4 to 4.5) have 70% to 80% of their roots in the top 57 cm, as shown in [51]. The soils in the study area have a pH$_{KCl}$ of 3.8 [30]. We assume that the farm household group A$_T$ reaches similar values (100%). We estimated 80% of this value for A$_U$, 60% for B$_T$, 40% for B$_U$, 30% for C$_T$, and 10% for C$_U$.

Biological fixation (IN2c)

In [49], the inputs through biological fixation from common beans (*Phaseolus vulgaris*) were estimated to be half of the total plant uptake in the above-ground biomass at 19.0 kg N ha^{-1} yr^{-1}, with an asymbiotic N fixation rate of 3 kg N ha^{-1} yr^{-1}, corresponding to a yield of 557 kg beans ha^{-1}. The fixed amount of N in the cultivation of common beans in Africa ranges from 8 to 58 kg N ha^{-1}, with 10% to 55% of the crop N derived from atmospheric N_2 [52]. We adopted the biological fixation rate from [49] because it was analysed for smallholder banana-coffee-based farming systems in the same study area, and applied it to the yields reached in each household group.

Organic fertiliser (IN3)

Organic fertiliser is usually a mixture of organic crop residues (IN3a), kitchen and food waste (IN3b), cooking ash (IN3c), livestock manure (IN3d), and (rarely) human excreta (IN3e). Farmers mix organic farm waste to produce *in situ*, pit, ring-hole, and trench compost, as described in detail in [24,25,53].

Crop residues (IN3a)

We estimated the amount of crop residues from the harvest, as presented in Table 5-2. Banana plants were estimated from the harvest of banana bunches. The formula was validated in the field with P_{ban} for banana plants and H_{ban} for harvested bunches of bananas:

$$P_{ban} = H_{ban} \times 1.2 \quad (4)$$

A banana plant should be replaced by another species every 10 to 15 years to minimise nutrient depletion, the incidence of pests, and diseases; this minimises dependency on synthetic fertilisers and pesticides [53]. Banana leaves and pseudostems are greater than twice the bunch weight [51], with 50% of the weight from leaves and 50% from pseudostems [53]. Assuming that a banana plant is cut down every 10 years [53] and one-third of the leaves fall as crop residues every year [55], the annual crop-residue factor is 0.15 for the pseudostem and 0.3 for banana leaves. For the leaves of evergreen coffee shrubs, we assume a crop-residue factor of 0.1. For maize, the crop-residue factor is 1:1.4 [55]. For cassava, we assume a factor of 1:1.2, and for beans and soybeans, we assume a factor of 1:2.1 according to [55].

Kitchen and Food Waste (IN3b)

About 16% of the dry weight of harvested banana bunches is pulp, 5% peel, and 0.5% stalk [49]. Peels and stalks are considered kitchen waste. About 45% of harvested coffee cherries consist of husks [49], which are exported and thereby not counted as kitchen waste. Bean husks, maize cobs, and cassava peel are also kitchen waste. Each ton of maize consists of approximately 180 kg cobs [54]. The peel of the cassava tuber accounts for 8% to 15% of the tuber [54]. Kitchen and food waste is the second-largest plant-based farm waste fraction. Generally, food waste remains low in the area as most households are food insecure. Most food waste occurs when harvested crops are not properly stored and spoil. The amounts of crop residues, along with kitchen and food waste, are multiplied by the nutrient values taken from Table A1 and summarised in Table 5-2.

Cooking Ash (IN4c)

Cooking ash remains after burning firewood and charcoal in either three-stone fires or improved cooking stoves. Cooking ash contains mineral nutrients such as P, K, calcium (Ca), and magnesium (Mg), but hardly any C, N, or sulphur (S) due to volatilisation during the oxidation process [56].Cooking ash may improve the compost's properties. According to [57], one smallholder household produces 23 kg ash yr^{-1} if they cook over three-stone fires, which contain a total of 1.0 kg P and no nitrogen.

Livestock Manure and Urine (IN3d)

We estimated the daily livestock manure production and multiplied the yearly amounts of manure with nutrient contents according to [50,58–61] and presented in Table 5-3. Manure is defined as a mixture of dung, possibly with urine and bedding [58]. In [61], the nutrient content in cattle manure in East Africa varied between 0.9% and 1.6% N, 0.3% and 0.6% P, and 1.3% and 2.4% K. Usually, the amount of chicken urine is too small to be relevant.

*Table 5-2***:** *Amounts of crop residues and kitchen and food waste of perennial and annual crops per household group and year. Dry weights are taken according to [54]. The amounts of crop residues depend on the crop yield. The crop yield varied among the trained households. T = trained, U = untrained, av. = mean value, min. = minimum value, max. = maximum value in this group of households, DM = dry matter, n.a. = not analysed.*

Annual crop residues	**Unit**	A_U	B_U	C_U	**Household groups** A_T			B_T			C_T		
					av.	*min*	*max*	*av.*	*min*	*max*	*av.*	*min*	*max*
Banana													
Plants	ha^{-1}	60	60	52	585	377	1,200	446	168	617	57	56	72
Leaves	kg ha^{-1}	494	300	90	6,585	3,300	15,000	4,495	840	5,400	285	210	360
Leaves, dry	kg DM ha^{-1}	68	49	14	988	535	2257	468	126	810	43	32	57
Pseudostems	kg ha^{-1}	225	157	49	3,293	1,657	7,570	2,228	400	2,700	143	105	180
Peel, fresh	kg ha^{-1}	357	233	70	5,114	2,563	11,657	2,403	652	4,194	221	163	280
Peel, dry	kg DM ha^{-1}	57	36	11	788	395	1,794	373	100	646	34	25	43
Stalk	kg ha^{-1}	35	23	6.9	579	253	1,157	239	64	414	22	16	28
Coffee													
Husks	kg ha^{-1}	90	49	49	135	49	225	68	49	90	23	14	49
Leaves	kg ha^{-1}	20	10	10	30	10	57	15	10	20	5	3	10
Leaves, dry	kg DM ha^{-1}	19	9.2	9.2	28	9.2	46	14	9.2	19	4.6	2.8	9.2
Beans													
Foliage	kg ha^{-1}	1,071	861	655	949	630	1,260	735	210	1,260	630	400	840
Straw	kg DM ha^{-1}	940	758	573	832	557	1,109	647	185	1,109	557	370	739
Maize													
Foliage	kg ha^{-1}	280	560	280	630	280	980	560	140	980	400	280	560
Stover	kg DM ha^{-1}	83	166	83	186	83	290	166	41	290	124	83	166
Cobs	kg ha^{-1}	36	72	36	81	36	126	72	18	126	57	36	72
Cobs, dry	kg DM ha^{-1}	33	66	33	74	33	115	66	16	115	53	33	66
Cassava													
Foliage	kg ha^{-1}	120	240	360	720	n.a.	n.a.	520	n.a.	n.a.	120	n.a.	n.a.
Foliage, dry	kg DM ha^{-1}	27	57	81	162	n.a.	n.a.	108	n.a.	n.a.	27	n.a.	n.a.
Peel, fresh	kg ha^{-1}	12	23	35	69	n.a.	n.a.	46	n.a.	n.a.	12	n.a.	n.a.
Peel, dry	kg DM ha^{-1}	10	20	30	60	n.a.	n.a.	40	n.a.	n.a.	10	n.a.	n.a.

Table 5-3: Daily livestock manure and urine production and nutrient concentration.

	Manure					Urine			
	Solid dung [I]	***Fresh dung*** [I]	***N***	***P***	***K***	***Amount*** [III]	***N***	***P***	***K***
	kg animal^{-1} d^{-1}		*in solid dung*			*L animal^{-1} d^{-1}*	*g L^{-1}*	*g L^{-1}*	*g L^{-1}*
Cattle	16.3	15–20	1.2 [II]	0.3 [II]	2.1 [II]	13.0–16.0	6.8 [IV]	n.d.	n.d.
Goat, sheep	1.5	0.9–3.0	1.5 [II]	0.2 [II]	3.0 [II]	0.5–2.0	3.0	n.d.	n.d.
Pig	1.0	1.2–4.0	2.5 [III]	0.5 [III]	0.7 [III]	2.0–6.0	n.d.	n.d.	n.d.
Chicken	0.1	0.02–0.2	1.4 [II]	0.3 [II]	1.8 [II]	n.r.	n.d.	n.d.	n.d.

n. r. = not relevant, n. d. = no data found.

[I] [58]. [II] In%, in kraals [59]. [III] In g kg^{-1} [50]. [IV] [60].

Urine can only be collected under zero-grazing conditions on a bedding floor, with daily collection of fresh manure and composting of urine-soaked bedding [58]. Livestock urine cannot be collected from bare soil, and dung is exposed to higher nitrogen losses [58]. The authors in [61] describe the nutrient losses between excretion and application. The nutrient losses during manure and urine collection and storage under different management systems are listed in Table 5 4. N losses vary from 20% to 100% for urine and 5% to 50% for dung, P losses vary between 3% and 30% in dung, and K losses vary between 5% and 80% in urine [61]. Farmers who practise zero-grazing usually keep their animals in a simple shelter with a fence and a roof for shade, but without a sealed floor—such as the kraal used in [61]. About 10% of the farmers in group AU and 40% in AT have bedding for their livestock. In group AU, 59% of the households use livestock manure in composting, 63% in BU, and 28% in CU [24], which is comparable to the management of the 'manure in compost pit' presented in [61]. Trained households use a higher proportion of their livestock manure than untrained households because they collect and store it. Farmers in group AT use between 90% and 100% of the livestock manure collected in the homegarden, group BT uses 50% to 90%, and group CT uses less than 50% [25].

Human Excreta (IN3e)

Human excreta are rarely used in composting, although they contain relatively high amounts of major nutrients, especially N in urine and P in faeces. We consider human excreta as the inflow (IN3e) if they are used to produce organic fertiliser, as outflow (OUT5) if they leach from the pit latrine, or as stock (STOCK3) if they stay in the pit latrines. The amount of human excreta depends on the residents' dietary intake of food and fluids, activities, sex, social status, anal cleansing methods, diarrhoea prevalence, and environmental conditions [62,63]. In [62], the median faecal wet mass production was 128 g pers.$^{-1}$ d^{-1} with a mean dry mass of 29 g pers.$^{-1}$ d^{-1} and 1.2 defecations per 24 h in healthy individuals. We assume that the amount and composition of nutrients in human faeces differ among the household groups due to their different diets and varying availability of food (Table 5-5).

Table 5-4: Nutrient losses during manure and urine collection and storage under different management systems summarised by [61]; K in dung and P in urine were not mentioned. T = trained, U = untrained.

	Average nutrient losses in%				
Collection and storage system	***Dung N***	***Dung P***	***Urine N***	***Urine K***	***Practised by household groups***
Open kraal/boma [I]	30	15	70	49	A_U, A_T, B_U, B_T
Manure in compost heap	20	10	60	40	not practised
Manure in compost pit	15	10	57	20	A_U, A_T, B_U, B_T
Deep litter compost (in situ compost)	15	10	55	25	all groups
Compact manure pit/heap and urine pit	10	5	40	10	A_U, A_T
Slurry pit (watertight, covered)	7	5	30	10	not practised

[I] A kraal or boma is a shelter with fences made of wood or bush branches. It stands on unsealed ground and usually has no bedding. It may have a roof for shade.

In the trained households, those in AT eat 3.0 meals d^{-1}, those in B_T eat 2.2 meals d^{-1}, and those in C_T eat 1.7 meals d^{-1} [25]. Thus, households in A_T are the reference group, and are assigned the value of 100%. In comparison, untrained households only have full access to food for 6.6 ± 3.1 months yr^{-1} in group A_U, 3.2 in group B_U, and 1.8 months yr^{-1} in group C_U [24]. Accordingly, households produce 100% of the nutrients (taken from [25]) in group A_T, 79% in A_U, 66% in B_T, 55% in C_T, 38% in B_U, and 22% in C_U. The authors in [64] measured 18 g N, 3.0 g P, and 44 g K kg^{-1} human faeces in South Africa.

Table 5-5: Amounts and nutrient concentrations of human faeces and urine per household group. T = trained, U = untrained, hh = household, p = person, d = day, yr = year.

Amounts and nutrients in human excreta	***Household groups***						
	Unit	***A_U***	***B_U***	***C_U***	***A_T***	***B_T***	***C_T***
Households	hh group^{-1}	58	52	44	296	262	198
Household size	pers. hh^{-1}	10.2	9.7	5.7	5.3	5.1	5.1
Human faeces							
Percentage of food intake [I]	% of A_T	79	38	22	100	66	55
Amount [II]	g p^{-1} d^{-1}	101	53	28	128	85	65
Amount [II]	kg p^{-1} yr^{-1}	37	18	10	47	31	24
N [III]	kg hh^{-1} yr^{-1}	6.8	3.1	1.1	4.5	2.8	2.2
P [III]	kg hh^{-1} yr^{-1}	1.1	0.5	0.2	0.7	0.5	0.4
K [III]	kg hh^{-1} yr^{-1}	16	7.6	2.6	11	6.9	5.3
Human urine							
Amount [II]	L p^{-1} d^{-1}	1.4	1.4	1.4	1.4	1.4	1.4
N [IV]	kg hh^{-1} yr^{-1}	62	59	35	32	31	31
P [IVI]	kg hh^{-1} yr^{-1}	3.5	3.3	1.9	1.8	1.7	1.7
K [IV]	kg hh^{-1} yr^{-1}	11	10	6.2	5.7	5.5	5.5

[I] Group A_T being the reference group at 100%. [II] According to [65].

The average amounts of human urine vary between 1.4 and 1.5 L d^{-1} according to [62,65]. Human urine contains the largest fractions of N and K released from the body [62]. About 86% of N excreted is included in urine and only 14% in faeces [62]. The authors in [66] found the mean nutrient concentrations in human urine to be 4.3 g N, 0.24 g P, and 0.76 g K L^{-1} human urine $pers.^{-1}$ d^{-1}, and we have used these values in this paper. In contrast to the variations in human faeces, we assume that human urine does not vary between household groups, since fluid intake (drinking water) does not fluctuate much.

Harvested Crops (OUT1)

The yields of perennial crops and annual crops for all household groups are presented in Table 5-6. Nutrient contents were taken from Table A1. About 20% of the nutrients in consumed food are taken up by the human body (STOCK1) [50].

Fodder (OUT2)

We estimate the amount of fodder from the amount of livestock manure, assuming that 20% of the nutrients contained in the fodder are absorbed by animals (STOCK2) and that 80% are excreted [50].

Wood (OUT3)

According to [57], one smallholder household consumes 1775 kg yr^{-1} firewood cooking on three-stone fires. This amount of firewood contains a total of 5.1 kg N and 1.0 kg P according to [57]. We estimated the K content in ashes to be 3.0 kg K according to [67,68]. We assume that the household groups A_U, B_U, A_T, and B_T consume the same amount of timber every year; groups C_U and C_T use half of that amount of timber. Additionally, we assume that households in groups A_T and A_U sell the same amount of wood on the market (OUT4), and B_T and B_U sell half of this amount; whereas groups C_U and C_T do not sell home-produced wood on the market.

Market (OUT4)

In all groups of households, the entire coffee harvest is sold to nearby coffee factories. Group A_T sells about 70% of its banana harvest, A_U and B_T sell about 50%, and B_U, C_T, and C_U sell about 30%. Of the bean harvest, 50% is sold in groups A_T, A_U, B_T, and B_U, and 20% in C_U and C_T. Of the maize and cassava harvest, 30% is sold in groups A_T, A_U, B_T, and B_U, and 10% in C_U and C_T.

Table 5-6: Annually harvested food crops after first processing them (peeling) before cooking for each household group. Dry weights are taken from [54]. T = trained, U = untrained, DM = dry mass, av. = mean value, min. = minimum value, max. = maximum value in this group of households.

Annual harvest		**Household groups**											
		A_U	B_U	C_U	A_T			B_T			C_T		
	Unit				av.	min.	max.	av.	min.	max.	av.	min.	max.
Banana													
Bunches	ha^{-1}	57	57	40	528	314	1,000	260	140	557	52	47	60
Bunch weight	kg	35	20	5.0	49	35	57	40	20	35	20	15	20
Pulp	kg ha^{-1}	1,116	744	223	16,331	8,184	37,200	7,738	2,083	13,392	707	521	893
Pulp, dry	kg DM ha^{-1}	240	160	52	3,552	1,760	8,000	1,664	492	2,880	152	112	192
Coffee, green	kg ha^{-1}	110	55	55	165	55	275	83	55	110	28	17	55
Beans (seeds)	kg DM ha^{-1}	494	365	276	401	267	535	312	89	535	267	178	356
Maize													
Grains	kg ha^{-1}	164	328	164	369	164	574	328	82	574	246	164	328
Grains, dry	kg DM ha^{-1}	152	26	3.9	17	120	10	14	15	2.3	7.1	5.9	1.6
Cassava													
Tuber, peeled	kg ha^{-1}	89	177	266	531	n.a.	n.a.	357	n.a.	n.a.	89	n.a.	n.a.
Tuber, peeled, dry	kg DM ha^{-1}	25	57	76	155	n.a.	n.a.	101	n.a.	n.a.	25	n.a.	n.a.

Sold Crop Residues (OUT5)

If the farmers sell crop residues or give them as a present to other farmers, an outflow of the farming system emerges in the nutrient balance.

Leaching (OUT6)

In [44], leaching of total dissolved nitrogen (TDN) at a 20 cm soil depth was found to be 27.7 ± 17.7 kg N ha^{-1} yr^{-1} with 2.0 ± 1.1, 19.2 ± 12.6, and 6.5 ± 4.2 kg N ha^{-1} yr^{-1} for NH_4^+, NO_3^- and DON, respectively. In [49], leaching of 21 kg N ha^{-1} yr^{-1} and 11 kg K ha^{-1} yr^{-1} was observed in Karagwe. The soils studied in [49] had (slightly) higher sand and clay content and less silt (60% sand, 14% silt, and 26% clay) than that in [48] (52% ± 13% sand, 44% ± 11% silt, and 7% ± 2% clay). These leaching values do not include leaching of human excreta from pit latrines.

Leaching from Pit Latrines (OUT7)

We estimate that 30% of the human excreta in unsealed pit latrines leaches into the aquifer.

River Discharge (OUT8)

The stream losses of TDN through river discharge are about 7.2 kg N ha^{-1} yr^{-1}, with 1.4, 3.8, and 2.0 kg N ha^{-1} yr^{-1} for NH_4^+, NO_3^-, and DON, respectively (Bauters *et al.* 2019). These values are comparable to the 6 kg N ha^{-1} yr^{-1} result in [49].

Gaseous Losses (OUT9)

Gaseous losses through the denitrification of soil are about 20 kg N ha^{-1} yr^{-1} [49]. They are higher if mineral fertiliser is applied to the soil [69].

Human Body (STOCK1)

We assume that the human body assimilates 20% of the nutrients contained in food [50].

Animal Body (STOCK2)

We assume that animals assimilate 20% of the nutrients contained in the fodder [50].

Pit Latrine (STOCK3)

We assume that 70% of human excreta remain in the pit latrine and are converted to sludge.

Soil (STOCK4)

The soil stores important amounts of nutrients. Soil data were taken from a recent field trial study on the ground at the Farmer Field School known as the MAVUNO Project [30]. Table 5 7 presents the soil data.

Vegetation Density

As several variables depend on the crop, tree, and livestock density, we estimated the vegetation densities for each farm household group as presented in Table 5-8. The lower the density of vegetation, the smaller the harvest and amount of litterfall, crop residues, and leaching. The lower the harvest, the lower the food security, products sold, and amount of nutrients in human excreta. The throughfall is presumed to be higher in less densely grown vegetation. The fewer the beans that are planted, the lower the biological nitrogen fixation rate. The more frequently and continuously the soil is covered with mulch or grass, the fewer the gaseous emissions that emerge from the soil. The less livestock there is, the smaller the amount of livestock manure. When livestock manure is quickly collected and composted, the gas losses from open manure storage are the lowest.

Scenarios

Afterwards, five scenarios were calculated. In the "business as usual" scenarios (S0), we applied the following principles based on the principles of "system dynamics": the more of A, the more of B (+); the more of A, the less of B (-). The following management scenarios were investigated and compared with S0:

S1. Human Urine,

S2. Legumes,

S3. CaSa-compost, and

S4. Combination of S1, S2, and S3.

S1 is called "Human Urine" because sustainable agricultural intensification can be supported by the application of human urine as suggested in [70]. In this scenario, 80% of human urine is separately collected, applied close to the ground in furrows along the plant rows, and immediately covered with soil.

S2 is called "Legumes" because in this scenario 0.5 t ha^{-1} *Crotalaria grahamiana* is incorporated into the soil. This should result in 17 kg N ha^{-1} being biologically fixed in the soil, as research revealed in [27].

Table 5-7: Soil properties of a vitric Andosol in the Karagwe district study area from field trials at the Farmer field school MAVUNO Project during 2014–2015; water depth in cm, ρ_B: bulk density in kg dm^{-3}, CEC_{eff}: effective cation exchange capacity in cmol kg^{-1}, BS: base saturation in%, TOC: total organic carbon in%, N_{tot}: total nitrogen in%, and C/N: carbon-nitrogen ratio [30].

Soil horizon	**Depth**	**Munsell Colour Code**	**Clay%**	**Silt%**	**Sand%**	**pH_{KCl}**	**TOC**	**N_{tot}**	**C/N**	**ρ_B**	**CEC_{eff}**	**BS**
Ap	20	2.5 YR 3/2	3.2	16	81	3.8	3.5	0.3	13	0.9	17	100
Ah	37	2.5 YR 3/2	3.6	13	83	3.8	2.7	0.2	13	0.9	11	97
B1	53	2.5 YR 2.5/3	2.2	16	82	n.a.	2.0	0.2	13	1.1	8.0	95
B2	74	2.5 YR 3/3	2.2	20	78	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
C	100+	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

n.a. = not analysed.

Table 5-8: Crop and tree density variation among the farm household groups. T = trained, U = untrained.

Agroforestry system stage	*Density*	%	*Household group*
Biodiverse, dense, well-managed farming system grown over several years/decades with old trees and sufficient nutrient input, soils covered with mulch throughout the year	*maximum*	100	Not reached by any group
Biodiverse, well-managed farming system with few older trees, integrated sustainable land use management, soils covered with grass throughout the year	*high*	80	A_T
Well managed but with lower density and traditional farming; soils are often covered with crop residues (*in situ* composting)	*moderate*	60	A_U
Moderately well managed, soils covered for some months of the year, lower yields, partial food insecurity	*low*	40	B_T, B_U
Poorly managed with very few crops and trees, frequent labour shortages, very low yields, food insecurity	*very low*	20	C_T, C_U

S3 is called "CaSa-compost". In this scenario, we predict that farm households will introduce the production of CaSa-compost as recommended in [30,56,57]. The term "CaSa" originates from a project called "Carbonisation and Sanitation" [30]. The CaSa-compost contains human faeces and urine, biochar from sawdust, crop residues, kitchen waste, and ash [30]. In the field trial in [30], a field sized 300 x 270 cm with a variety of vegetables was provided, to which 8.3 dm^3 m^{-2} CaSa-compost was applied. In S3, we adjusted this application rate to a field size of 600 m^2, to which the farmers applied 6.4 kg m^{-2} compost. In S4, we combined the impacts of S1, S2, and S3.

5.3 Results

The nutrient inflows, outflows, and the resulting nutrient balances (NB) in the homegardens of all household groups are presented in Table 5-9. The atmospheric deposition (IN1), litterfall (IN2b), and deep capture (IN2b) per hectare are equal for all household groups. Biological nitrogen fixation (IN2c) depends on the yield of common beans. Organic materials that emerge in the homegarden are summarised as organic fertiliser (IN3). Organic fertiliser is the main input (IN3) of nutrients into homegardens, whereas the crop harvest (OUT1) is the main outflow, followed by woodcutting and the harvest of fodder. All residues of coffee cherries are exported by all households. Huge amounts of N and K in group AT originate from large amounts of livestock manure (IN4d), which are collected in the homegardens. Nutrient inflows from livestock manure from the grassland is not considered in the NB because the manure is not collected and thus does not return to the homegardens.

Table 5-9: The "business as usual" scenario for each trained and untrained farm household group, along with scenario S1 (using 80% of the human urine in accordance with [70,71]), S2 (incorporating 0.5 t of Crotalaria grahamiana into the soil in accordance with [72]), S3 (applying 6.4 kg m^{-2} of CaSa-compost to 600 m^2 as per [30,73]), and S4, combining S1, S2, and S3. All values are given in kg ha^{-1} hh^{-1} yr^{-1}. U = untrained, T = trained, n.d. = no data, NB = nutrient balance.

Inflows, outflows, and nutrient budgets in farm household groups																		
Flow	***A$_U$***			***B$_U$***			***C$_U$***			***A$_T$***			***B$_T$***			***C$_T$***		
Nutrient (kg ha^{-1} yr^{-1})	***N***	***P***	***K***	***N***	***P***	***K***	***N***	***P***	***K***	***N***	***P***	***K***	***N***	***P***	***K***	***N***	***P***	***K***
IN1 Atmospheric deposition	4.4	0.7	2.9	4.4	0.7	2.9	4.4	0.7	2.9	4.4	0.7	2.9	4.4	0.7	2.9	4.4	0.7	2.9
IN2 Input by plants and trees	30	1.1	5.3	20	0.6	2.6	12	0.1	0.7	36	1.4	6.6	30	0.8	4.0	18	0.4	2.0
IN3 Organic fertiliser	102	15	153	86	15	142	41	9.6	64	373	64	565	169	29	267	54	8.1	65
Crop residues	4.4	1.1	10	4.9	2.1	14	4.6	3.1	13	39	7.3	94	20	4.7	50	3.3	1.1	9.7
Banana leaves	1.9	0.1	3.3	1.2	0	2.2	0.4	0	0.7	27.2	1.0	48	12.9	0.5	23	1.2	0	2.1
Banana pseudostems	0.2	0	1.4	0.1	0	0.9	0.0	0	0.3	2.7	0.3	20	1.3	0.1	9.6	0.1	0	0.9
Coffee leaves	0.7	0	0.0	0.4	0	0.0	0.4	0	0.0	1.1	0	0.1	0.6	0	0.1	0.2	0	0.0
Maize stover	0.5	0	2.2	1.0	0	4.4	0.5	0	2.2	1.1	0.1	5.0	1.0	0	4.4	0.7	0	3.3
Cassava foliage	1.1	1.0	3.4	2.2	2.0	6.8	3.3	3.0	10	6.7	6.0	20	4.5	4.0	14	1.1	1.0	3.4
Kitchen waste	25	1.8	20	20	1.9	18	16	1.7	14	26	2.9	35	20	2.5	29	15	1.4	14
Cooking ash [I]	0	1.0	n.d.	0	1.0	n.d.	0	1.0	n.d.	0	1.0	n.d.	0	1.0	n.d.	0	1	n.d.
Livestock manure	68	10	118	53	9.0	103	16	2.2	33	309	53	437	129	21	188	36	4.6	41
Livestock manure, grassland [II]	540	91	634	262	43	298	3.3	0	0	2,139	357	2,499	822	137	961	2.5	0	0
Human urine	4.8	0.9	5.2	7.4	1.4	6.4	4.3	1.7	3.2	0 [III]	0	0	0	0	0	0	0	0
Total nutrient inflow	144	17	161	125	17	147	66	10	67	414	66	575	204	30	274	77	8	71
OUT1 Harvest	52	6.0	36	42	5.9	32	32	4.6	25	90	14	115	56	9.0	65	30	4.2	23
Banana pulp	2.0	0.4	1.6	1.3	0.2	1.1	0.4	0.1	0.3	29	5.3	24	14	2.5	11	1.3	0.2	1.0
Banana peel	0.6	0.1	2.7	0.4	0.0	1.8	0.1	0.0	0.5	9.0	0.9	39.3	4.3	0.4	18.6	0.4	0.0	1.7
Banana stalk	0.1	0.0	0.6	0.0	0.0	0.4	0.0	0.0	0.1	1.0	0.2	9.1	0.5	0.1	4.3	0.0	0.0	0.4
Coffee beans	2.5	0.3	2.5	1.3	0.1	1.2	1.3	0.1	1.2	3.8	0.4	3.7	1.9	0.2	1.9	0.6	0.1	0.6
Coffee husks	1.8	0.2	2.5	0.9	0.1	1.2	0.9	0.1	1.2	2.7	0.3	3.7	1.4	0.1	1.9	0.5	0.0	0.6
Common beans	19	2.6	5.3	15	2.1	4.3	12	1.6	3.2	17	2.3	4.7	13	1.8	3.6	11	1.6	3.1
Bean waste	24	1.5	17	19	1.2	14	14	0.9	11	21	1.3	15	16	1.0	12	14	0.9	10
Maize grains	0.4	0.4	0.5	0.9	0.9	1.1	0.4	0.4	0.5	1.0	1.0	1.2	0.9	0.9	1.1	0.7	0.6	0.8

Inflows, outflows, and nutrient budgets in farm household groups																		
Flow	***A_U***			***B_U***			***C_U***			***A_T***			***B_T***			***C_T***		
Nutrient (kg ha^{-1} yr^{-1})	***N***	***P***	***K***	***N***	***P***	***K***	***N***	***P***	***K***	***N***	***P***	***K***	***N***	***P***	***K***	***N***	***P***	***K***
Maize cobs	0.5	0.2	1.6	1.0	0.5	3.2	0.5	0.2	1.6	1.2	0.5	3.6	1.0	0.5	3.2	0.8	0.3	2.4
Cassava tubers	0.5	0.2	1.1	1.0	0.3	2.2	1.5	0.5	3.2	3.0	1.0	6.5	2.0	0.6	4.3	0.5	0.2	1.1
Cassava peel	0.2	0.2	0.6	0.4	0.4	1.3	0.6	0.6	1.9	1.3	1.3	3.9	0.8	0.8	2.6	0.2	0.2	0.6
Food (part of OUT1)	11	1.9	4.6	10	2.1	5.1	11	2.1	6.2	20	4.1	15	16	3.2	11	11	2.1	4.9
Banana pulp	1.0	0.2	0.8	0.9	0.2	0.8	0.3	0.1	0.2	8.8	1.6	7.1	7.0	1.3	5.6	0.9	0.2	0.7
Common beans	9.6	1.3	2.7	7.7	1.1	2.1	9.4	1.3	2.6	8.5	1.2	2.3	6.6	0.9	1.8	9.1	1.2	2.5
Maize grains	0.3	0.3	0.4	0.6	0.6	0.7	0.4	0.4	0.5	0.7	0.7	0.8	0.6	0.6	0.7	0.6	0.6	0.7
Cassava tubers	0.3	0.1	0.8	0.7	0.2	1.5	1.3	0.4	2.9	2.1	0.7	4.5	1.4	0.4	3.0	0.4	0.1	1.0
OUT2 Fodder	17	2.6	29	13	2.3	26	4.1	0.5	8.2	116	20	164	32	5.2	47	8.9	1.1	10
OUT3 Wood	27	5.3	9.0	23	4.4	7.5	14	2.7	4.5	27	5.3	9.0	23	4.4	7.5	14	2.7	4.5
Firewood	9.1	1.8	3.0	9.1	1.8	3.0	9.1	1.8	3.0	9.1	1.8	3.0	9.1	1.8	3.0	9.1	1.8	3.0
Timber	9.1	1.8	3.0	9.1	1.8	3.0	4.5	0.9	1.5	9.1	1.8	3.0	9.1	1.8	3.0	4.5	0.9	1.5
For sale	9.1	1.8	3.0	4.5	0.9	1.5	0.0	0.0	0.0	9.1	1.8	3.0	4.5	0.9	1.5	0.0	0.0	0.0
Nutrients withdrawn by plants	105	16	78	82	13	66	50	7.8	37	242	41	291	116	20	121	53	8.0	37
OUT4 Sold on the market	25	4.1	14	11	1.8	6.6	5.0	0.7	4.2	54	9.2	68	25	4.5	27	4.1	0.6	3.3
Banana	1.3	0.2	2.5	0.5	0.1	1.0	0.2	0.0	0.3	28	4.5	50	9.3	1.5	17	0.5	0.1	0.9
Coffee	4.3	0.4	5.0	2.2	0.2	2.5	2.2	0.2	2.5	6.5	0.6	7.5	3.2	0.3	3.7	1.1	0.1	1.2
Beans	9.6	1.3	2.7	3.1	0.4	0.9	2.3	0.3	0.6	8.5	1.2	2.3	6.6	0.9	1.8	2.3	0.3	0.6
Maize	0.3	0.2	0.6	0.2	0.1	0.4	0.1	0.1	0.2	0.7	0.4	1.4	0.6	0.4	1.3	0.1	0.1	0.3
Cassava	0.2	0.1	0.5	0.1	0.1	0.3	0.2	0.1	0.5	1.3	0.7	3.1	0.8	0.4	2.1	0	0	0.2
Wood	9.1	1.8	3.0	4.5	0.9	1.5	0.0	0.0	0.0	9.1	1.8	3.0	4.5	0.9	1.5	0	0	0
OUT5 Residues given away	0	0	0	0	0	0	1.4	0.9	4.0	0	0	0	0	0	0	1.0	0.3	2.9
OUT6 Leaching from soil/runoff	21	n.d.	11	21	n.d.	11	21	n.d.	11	21	n.d.	11	21	n.d.	11.0	21	n.d.	11
OUT7 Human excreta	24	4.6	28	20	3.8	18	11.2	2.1	8.7	13	2.5	17	11.6	2.2	12	11	2.1	11
Faeces	5.4	1.1	17	2.5	0.5	7.6	0.8	0.2	2.6	3.6	0.7	11	2.3	0.5	6.9	1.7	0.4	5.3
Urine	19	3.5	11	18	3.3	11	10	1.9	6.2	9.7	1.8	5.7	9.3	1.7	5.5	9.3	1.7	5.5
OUT8 Discharge	6.0	n.d.	n.d.	6.0	n.d.	n.d.	6.0	n.d.	n.d.	6.0	n.d.	n.d.	6.0	n.d.	n.d.	6.0	n.d.	n.d.

Inflows, outflows, and nutrient budgets in farm household groups																		
Flow	***A_U***			***B_U***			***C_U***			***A_T***			***B_T***			***C_T***		
Nutrient (kg ha^{-1} yr^{-1})	***N***	***P***	***K***	***N***	***P***	***K***	***N***	***P***	***K***	***N***	***P***	***K***	***N***	***P***	***K***	***N***	***P***	***K***
OUT9 Gaseous losses, soil	20	0	0	20	0	0	20	0	0	20	0	0	20	0	0	20	0	0
OUT10 Leaching from pit latrine	7.2	1.4	8.3	6.0	1.1	5.4	3.4	0.6	2.6	4.0	0.8	5.0	3.5	0.7	3.7	3.3	0.6	3.3
STOCK1 Human	2.3	0.4	0.9	2.0	0.4	1.0	2.3	0.4	1.2	4.0	0.8	3.0	3.1	0.6	2.2	2.2	0.4	1.0
STOCK2 Animal	3.4	0.5	5.9	2.7	0.5	5.1	0.8	0.1	1.6	23	4.0	33	6.4	1.0	9.4	1.8	0.2	2.0
STOCK3 Pit latrine	90	12	102	72	10	80	45	7.3	43.7	9.3	1.8	11.6	110	17	146	85	11	77
S0. Business as usual																		
Inflow	137	17	161	111	17	147	57	10.4	67	414	66	575	204	30	274	77	9.2	70
Total, outflow	-213	-19	-119	-191	-17	-100	-139	-15	-62	-317	-42	-315	-192	-21	-143	-133	-10.1	-59
Nutrient balance	**-76**	**-2**	**43**	**-81**	**-1**	**47**	**-82**	**-5**	**5**	**97**	**24**	**260**	**12**	**9**	**131**	**-56**	**-1**	**11**
S1. Human urine used																		
Inflow	152	17	161	125	17	147	66	10	67	422	66	575	211	30	274	84	9	70
Outflow	-197	-15	-102	-173	-13	-84	-125	-9	-55	-309	-40	-309	-185	-19	-137	-127	-9	-57
Nutrient balance	**-44**	**2**	**59**	**-48**	**4**	**64**	**-60**	**2**	**12**	**112**	**26**	**265**	**27**	**11**	**137**	**-42**	**1**	**13**
S2. Legumes planted																		
Inflow	169	17	161	142	17	147	83	10	67	439	66	575	228	30	274	101	9	70
Outflow	-213	-19	-119	-191	-17	-100	-139	-15	-62	-317	-42	-315	-192	-21	-143	-133	-10	-59
Nutrient balance	**-44**	**-2**	**43**	**-49**	**-1**	**47**	**-57**	**-5**	**5**	**122**	**24**	**260**	**36**	**9**	**131**	**-31**	**-1**	**11**
S3. CaSa-compost used [IV]																		
Inflow	144	21	178	117	20	164	64	14	84	421	70	592	211	34	291	84	13	86
Outflow	-195	-14	-94	-172	-13	-80	-125	-9	-54	-308	-40	-304	-184	-19	-134	-126	-8	-54
Nutrient balance	**-50**	**6**	**84**	**-54**	**7**	**84**	**-61**	**5**	**30**	**113**	**30**	**288**	**27**	**15**	**157**	**-42**	**4**	**33**
S4. Combination of S1+S2+S3																		
Inflow	176	21	178	149	20	164	89	14	84	446	70	592	235	34	291	108	13	86
Outflow	-195	-14	-94	-172	-13	-80	-125	-9	-54	-308	-40	-304	-184	-19	-134	-126	-8	-54
Nutrient balance	**-19**	**6**	**84**	**-23**	**7**	**84**	**-36**	**5**	**30**	**138**	**30**	**288**	**51**	**15**	**157**	**-17**	**4**	**33**

[I] Cooking ash is not used as compost by all household groups. A_U uses 49% of the ash, B_U 54%, C_U 44%, A_T 100%, B_T 50%, and C_T 0%. Unused ash is included in STOCK3.

[II] Not included in the nutrient balance of the homegarden. Trained households do not collect livestock manure from the grassland.

[III] Trained households do not apply human urine as organic fertiliser to the fields.

[IV] Includes eco-sanitation with urine-diverted toilets and avoids pit latrines, thus avoiding leaching from pit latrines. Also, only half of the human excreta is considered as OUT7.

Table 5-10: Annual manure production and nutrient concentrations of all household groups. U = untrained, T = trained.

Annual manure production and nutrient concentrations		Household groups					
	Unit	A_U	A_T	B_U	B_T	C_U	C_T
Cattle, homegarden							
Dung	$kg\ yr^{-1}$	915	9,153	1,373	2,746	0	0
N	$kg\ yr^{-1}$	11	110	16	33	0	0
P	$kg\ yr^{-1}$	2.7	27	4.1	8.2	0	0
K	$kg\ yr^{-1}$	19	192	29	58	0	0
Urine	$m^3\ yr^{-1}$	0.7	7.3	1.1	2.2	0	0
N	$kg\ yr^{-1}$	5.0	57	7.4	15	0	0
Cattle, grassland							
Dung	$kg\ yr^{-1}$	30,205	118,990	14,187	45,765	0	0
N	$kg\ yr^{-1}$	362	1,408	170	553	0	0
P	$kg\ yr^{-1}$	91	357	43	137	0	0
K	$kg\ yr^{-1}$	634	2,539	298	961	0	0
Urine	$m^3\ yr^{-1}$	24	95	11	37	0	0
N	$kg\ yr^{-1}$	164	649	77	252	0	0
Goat, sheep, pig							
Dung	$kg\ yr^{-1}$	3,011	5,475	2,464	3,285	1,095	821
N	$kg\ yr^{-1}$	49	82	37	53	16	12
P	$kg\ yr^{-1}$	6.0	11	4.9	6.6	2.2	1.6
K	$kg\ yr^{-1}$	90	164	74	99	33	25
Urine	$m^3\ yr^{-1}$	3.0	5.5	2.5	3.3	1.1	0.8
N	$kg\ yr^{-1}$	9.0	16	7.4	10	3.3	2.5
Chicken							
Dung	$kg\ yr^{-1}$	365	3,650	0	1,460	0	730
N	$kg\ yr^{-1}$	12	117	0	47	0	23
P	$kg\ yr^{-1}$	1.5	15	0	5.8	0	2.9
K	$kg\ yr^{-1}$	8.0	80	0	32	0	16

The high nutrient charges in the total inputs in the groups A_T, B_T, A_U, and B_U can be explained by the relatively high numbers of livestock kept in their homegardens, and by fodder imports from the surrounding grassland and forests. The annual production of nutrients in human excreta per household is presented in Table 5-11. The amount depends on the household size. The amount of N and K included in IN3 follows the order $A_T > B_T > A_U > B_U > C_T > C_U$. For phosphorus (P), the order is similar, except for $A_U = B_U$ and $C_U > C_T$.

In the "business as usual" scenario (S0), the trained household groups A_T and B_T have an entirely positive nutrient budget, with 97 kg N, 24 kg P, and 260 kg K $ha^{-1}\ hh^{-1}\ yr^{-1}$, and 12 kg N, 9 kg P, and 131 kg K $ha^{-1}\ hh^{-1}\ yr^{-1}$, respectively.

Table 5-11: Annual production of human excreta and nutrients in human excreta per household group. U = untrained, T = trained, p = person, hh = household.

Human excreta			**Household groups**					
		Unit	**A_U**	**B_U**	**C_U**	**A_T**	**B_T**	**C_T**
Number of farm households		hh group^{-1}	58	52	44	296	262	198
Homegarden size (average)		ha	2.8	1.8	0.6	1.4	0.7	0.5
Household size		p hh^{-1}	10.2	9.7	5.7	5.3	5.1	5.1
Amount of faeces		kg hh^{-1} yr^{-1}	376	172	59	248	157	122
	N	kg hh^{-1} yr^{-1}	6.8	3.1	1.1	4.5	2.8	2.2
	P	kg hh^{-1} yr^{-1}	1.1	0.5	0.2	0.7	0.5	0.4
	K	kg hh^{-1} yr^{-1}	17	7.6	2.6	11	6.9	5.3
Amount of urine		L hh^{-1} yr^{-1}	5,212	4,957	2,913	2,708	2,606	2,606
	N	kg hh^{-1} yr^{-1}	69	62	36	37	34	33
	P	kg hh^{-1} yr^{-1}	4.6	3.8	2.1	2.5	2.2	2.1
	K	kg hh^{-1} yr^{-1}	28	18	9	17	12	11
Total amounts of nutrients in human excreta …								
… after 70% ammonia losses in urine								
	N	kg hh^{-1} yr^{-1}	25	21	11	14	12	11
… used in composting								
	N	kg hh^{-1} yr^{-1}	4.8	7.4	4.3	0.0	0.0	0.0
	P	kg hh^{-1} yr^{-1}	0.9	1.4	1.7	0.0	0.0	0.0
	K	kg hh^{-1} yr^{-1}	5.2	6.4	3.2	0.0	0.0	0.0
	N	kg hh^{-1} ha^{-1} yr^{-1}	1.7	4.1	7.1	0.0	0.0	0.0
	P	kg hh^{-1} ha^{-1} yr^{-1}	0.3	0.8	2.8	0.0	0.0	0.0
	K	kg hh^{-1} ha^{-1} yr^{-1}	1.9	3.6	5.4	0.0	0.0	0.0
… not used (pit latrine)								
	N	kg hh^{-1} yr^{-1}	21	13	7.2	21	13	10
	P	kg hh^{-1} yr^{-1}	3.7	2.5	1.4	3.1	2.0	1.5
	K	kg hh^{-1} yr^{-1}	22	12	5.5	8	5	4

The household groups A_U, B_U, C_U, and C_T have a negative balance for N and P. The flows of N in the groups AT and C_U are visualised in Figures 5-4 and 5-5. This is where the differences are the highest between these two groups. The differences in the N flows of biomass and waste are illustrated by the thickness of the arrows. The thicker the arrows, the higher the N charge. The amount of unused manure remains high in households where most livestock are kept on grassland. The nutrient losses from manure storage are already considered in these NBs.

The NB of the trained group of households A_T and B_T that implemented the measures taught in the SLM training is considerably more positive than that of the best-performing untrained group (A_U). A similar trend can be found by comparing the moderately performing untrained group of households (B_U) with the corresponding trained group (B_T). The NB of the A_U group, however, is not nearly as positive as that of the B_T group

The NB for group C_T is also more positive than the NB in group C_U, although the NB of the group C_T is also in the negative range for N and P. Compared to the baseline scenario (S0), the NB would improve in all groups of households under all management scenarios. Untrained households improve their nutrient balances under all management scenarios, but the N budget remains negative. The differences in the NB under all scenarios for the households in groups C_U and C_T are relatively small due to the low crop yields and resulting crop residues, and low amounts of livestock manure. In summary, the NBs are most positive under S4.

5.4 Discussion

5.4.1 Methodology

We calculated the nutrient balances (NBs) according to the best of our knowledge and systematic literature research, e.g., [46,49,50,54,57,58,62,66,67,71,73]. Nevertheless, these values are primarily estimates based on derivations from the values found in the literature, which were then transferred to the study area investigated in this paper. We did not carry out any field measurements, and the nutrient balances in the field may deviate considerably from the values estimated here. However, this is an initial assessment of nutrient depletion due to agricultural production and the possible nutrient inputs that could compensate for this depletion. Our research also identifies opportunities to help smallholder farmers improve their nutrient management and thus increase their yields, and also highlights the positive achievements of the farmer field school MAVUNO Project, which are presented here as a best-practice example for organisations with similar goals (e.g., increasing soil fertility, biodiversity, and food security).

5.4.2 Results

As hypothesised, the NBs of the trained farm households are more balanced than those of the untrained households due to the implementation of sustainable land management (SLM) practices. The consistently positive N, P, and K contents in groups A_T and B_T are mainly achieved by the recycling of livestock manure and the relatively high production of plant-based biomass and the resulting amount of organic fertiliser.

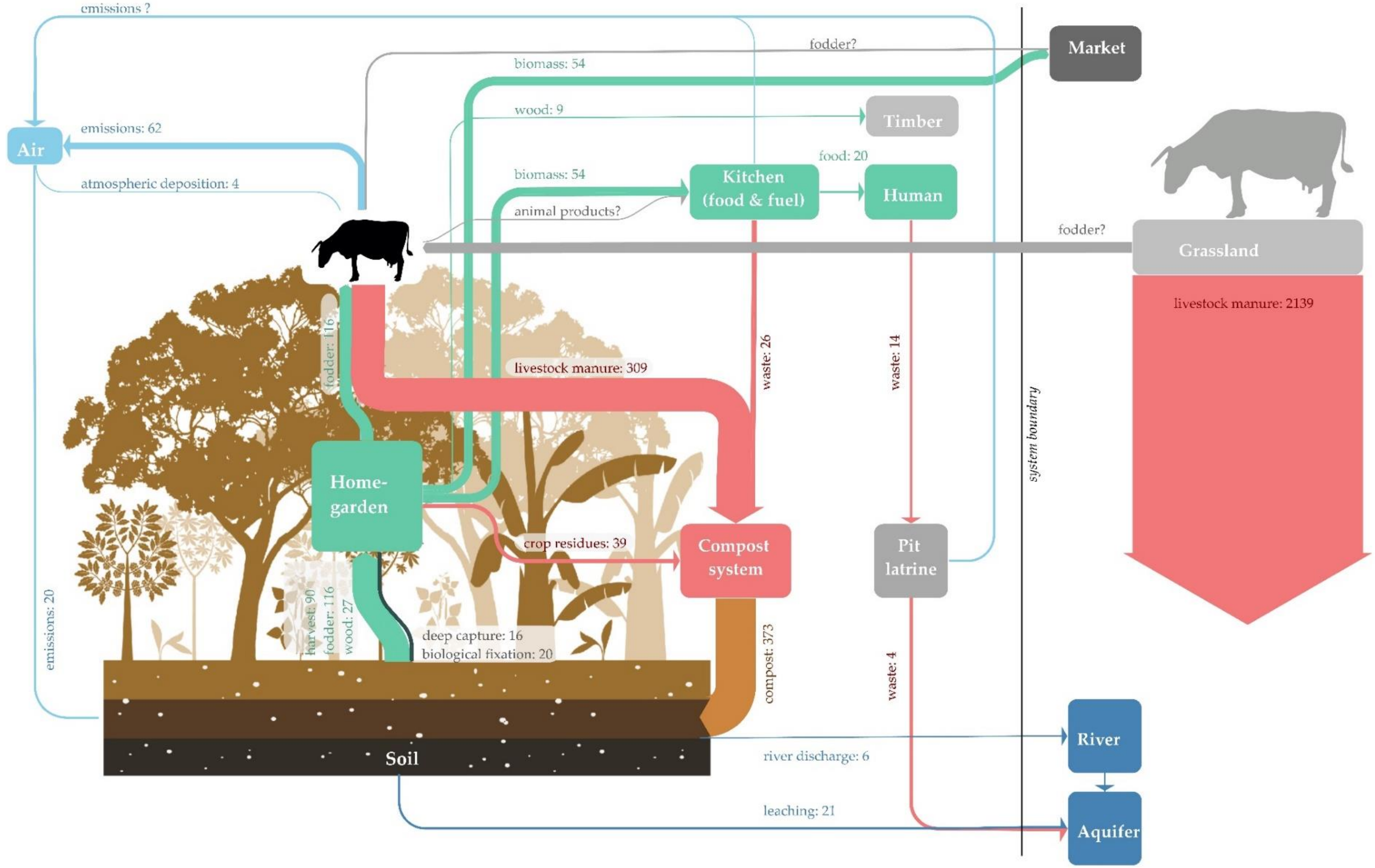

Fig. 5-3: Main nitrogen flows in household group A_T (non-vulnerable to food insecurity, trained farm households). All values in kg N ha^{-1} hh^{-1} yr^{-1}. (Design of background picture: Claudia Matthias, modified by Atiqah Fairuz Salleh)

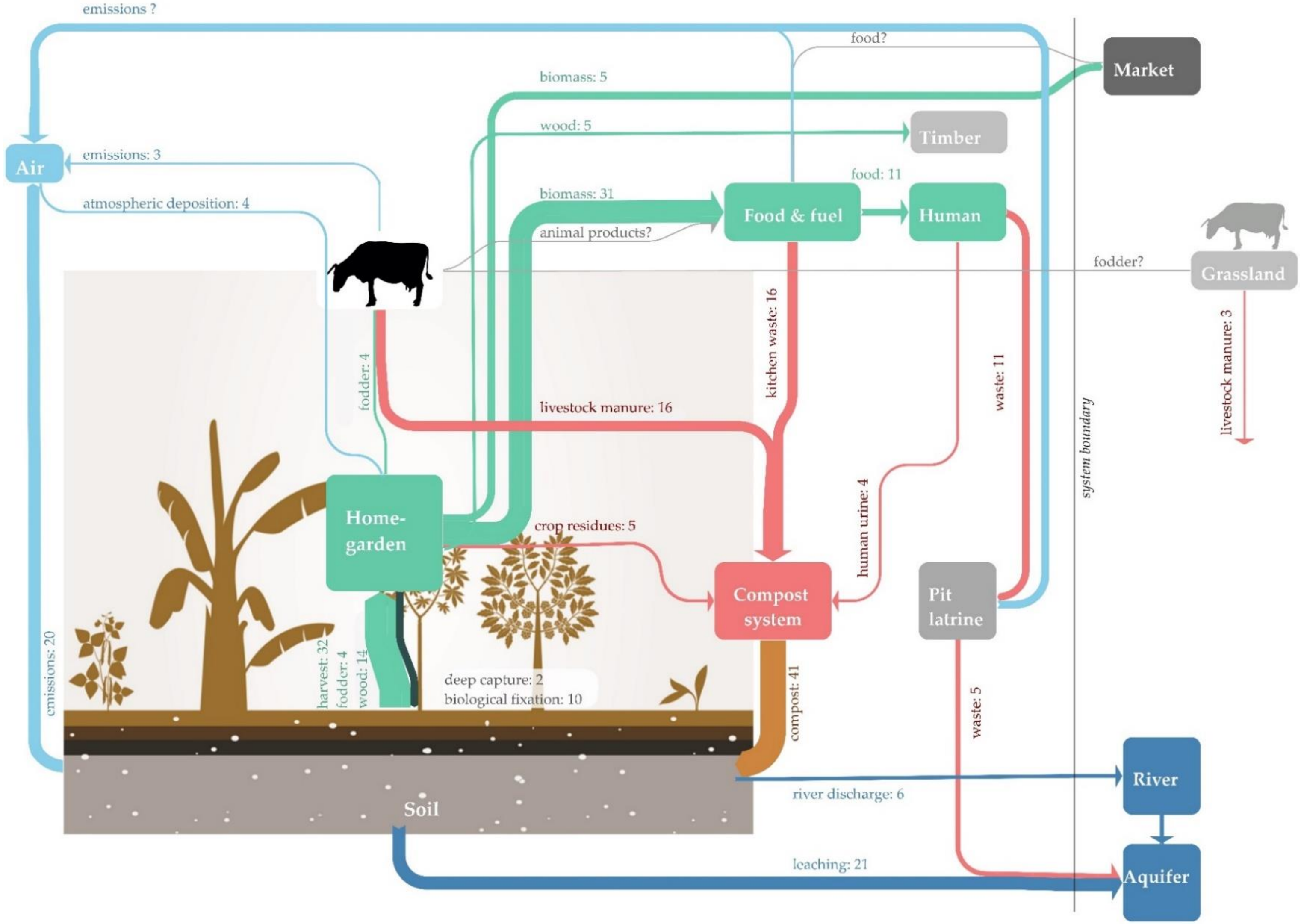

Fig. 5-4: Main nitrogen flows in household group Cu (most vulnerable to food insecurity, untrained farm households). All values in kg N ha^{-1} hh^{-1} yr^{-1}. (Design of background picture: Claudia Matthias, modified by Atiqah Fairuz Salleh)

These values are comparable to those of the farm households studied in the same area in [22], in which the livestock manure from zero-grazing in the homegardens resulted in the highest nutrient inflow. In our analysis, the nutrient concentrations of livestock manure were taken from the kraals in [59], where nutrient losses through volatilisation were already considered according to [61]. Nutrient losses can be minimised by improving the shelter and storage of collected manure; e.g., some of the livestock urine can be collected in bedding, which is then immediately covered with soil in compost pits [58,61]. However, the NBs vary greatly depending on how much fodder a household cultivates in its own homegarden and how much it imports from outside. The household group A_T produces only 30% of the fodder required for the animals kept in the homegarden, and all other groups produce less than 20%.

If the farmers were to grow the entire fodder demand for their cattle themselves, the NBs would be clearly negative in the baseline scenario (S0), even under the management scenario S4, e.g., for group A_T under S4 the NB would be -142 kg N, -19 kg P, and -106 kg K ha^{-1} hh^{-1} yr^{-1}. Figures 5-3 and 5-4 clearly show the differences in nutrient flows between the most successful trained group of farmers A_T and the most unsuccessful untrained group C_U. Although the illustrations only show the nitrogen cycles, the differences in the quantities for the P and K cycles are comparable as shown in Table 5-9. Considerably higher amounts of nutrients circulate in the homegardens of the A_T group than in the C_U group. Less successful farmers remove fewer nutrients from their soil in absolute numbers. However, they also add fewer nutrients and implement fewer measures that have a positive effect on nutrient balance and availability. For example, they enrich the soil less with humus, which is essential to store nutrients in a plant-available way, and mulch their soil less often, which leads to faster drying out of the soil and less plant-available water. We suspect that the households in the C_U and C_T groups are also among those that had worse farming conditions from the beginning. We observed during our survey that refugees from neighbouring countries often settled on land that was characterised by little or no vegetation, and probably by high soil degradation and low nutrient levels in the soil.

Besides, the potential for the additional use of livestock manure from grassland seems to be enormous at first glance (*cf.* Fig. 5-3). However, this applies only if the cattle graze solely on the grassland (outside the system boundary of the NB) and do not eat fodder grown in the homegarden (inside the system boundary). In contrast, manure collection from grassland would have a negative impact on the NB of the grassland, where overgrazing can lead to long-term environmental damage, such as a reduction in vegetation, less humus formation, nutrient depletion, an exposed soil surface, and soil erosion by runoff (*cf.* [74]).

We assume that the implementation of the management scenarios investigated in this paper would improve the NB of untrained households. Thus, untrained households can considerably improve the overall NB of their homegarden via the incorporation of herbaceous legumes (according to [75]), the use of urine (according to [76]), and the additional production of CaSa-compost (human faeces, biochar from sawdust, crop residues, kitchen waste, and ash) (according to [21,51,56]). However, all untrained farm households remain in a negative range for N, P, and K. Successful implementation of the management scenarios would depend on various conditions, such as farm and soil management, soil nutrient status, water balance, and the timing and duration of rainfall.

In general, balance deficits can be eliminated or enhanced by various effects. Untrained farmers would additionally improve the NB in their homegardens if they were to implement training on SLM as recommended by the Farmer field school MAVUNO Project. Effects on the NB are achieved via the following measures: minimising erosion due to runoff, nutrient-efficient compost production, (rain)water supply, and mulching. Nutrient losses from erosion due to runoff on slopes can be minimised by terracing and trench composting [24,75,76]. Additionally, improper compost production (e.g., no cover or shade over the compost trench) may lead to a higher volatilisation of nitrogen [25]. Further, the amount of rainfall determines the rate of leaching of nutrients [50]. Leaching might decrease over time if the rainfall decreases due to climate change (*cf.* [13]). On the other hand, changes in rainfall patterns exacerbate crop cultivation and livestock-keeping in Tanzania and require small-scale water harvesting technology to overcome water scarcity through irrigation [13,77-79]. Banana plants depend on high soil water availability; thus, the mulching of soil surfaces to reduce unproductive water loss from the soil becomes unavoidable. It should be noted that in order to promote the deep root growth of banana plants, the ground around the banana plant should be left free up to a radius of several centimetres [80].

Not all household groups will be able to engage in composting, due to the extra work required and their inability to hire extra labour, especially not C_U and C_T. The household groups C_U and C_T are vulnerable to food insecurity and have a weak socio-economic position. The households in group C_T show some improvements in their socio-economic status compared to C_U, but are still socio-economically weak and vulnerable to food insecurity (*cf.* [24,25]). Poor soil and nutrient management are two reasons for these problems.

Moreover, treatment with urine and human faeces offered higher water productivity in [79]. Trained households do not apply human urine to their fields by the same methods employed by untrained households, although this may change in the future (increasing tendency) if human urine is safely used to enrich soils with N and P (e.g., [56,70]). In groups B_U,

C_U, and C_T, the nutrient content in human excreta might have been overestimated because the nutrient contents are based on healthy and food secure persons. These groups of households are not food secure throughout the year, as shown in [24,25]. Data on human excreta under food shortage conditions is not available in this study area. In addition, biochar from sawdust and human faeces has the positive effects of long-term humus accumulation, nutrient storage in humus, and carbon sequestration [81-83]. Farmers may have no problem with the origin of organic amendments if they have a positive effect on the soil, but caution should be taken in the case of any rejection of products derived from human excreta [83] and if the soil health is affected [84].

In addition, as long as the nutrient status of the soil is not analysed on every farm and the nutrient flows between household groups remain unclear, we cannot be sure whether the additional application of synthetic fertiliser is necessary [85]. However, due to its high cost, detailed soil sampling is not feasible. We assume that nutrient depletion is high in these small-scale systems, as has been shown for banana-coffee-based farming systems in Uganda [86] and in annual cropping systems in NW Tanzania [56]. We also assume that households in the groups A_T, B_T, and A_U operate based on the same "nutrient costs" of the other groups (B_U, C_T, and C_U). This hypothesis can only be confirmed or disproven if the nutrient flows between the groups are examined in detail by additional interviews with the farmers concerned. Nevertheless, trained farm households have transformed a part of their homegardens into densely grown and biodiverse agroforestry systems with almost closed nutrient cycles. Thus, not only were the NBs in these homegardens improved, but also the food security and prosperity of their families (*cf.* [25]).

As a final remark, NBs are highly dependent on many variables. Farm management improves under SLM and different management scenarios, especially with respect to the use of waste, fodder production, treatment of the soil, mulching, available mineral nitrogen and non-available nitrogen in the soil and soil water, amendments to organic fertiliser, plant density, harvest time, exposure to sunlight, length of the dry season, irrigation in the driest months, the decomposition rate of organic materials, gaseous losses, the weather, and the climate [30,56,70,71,79,87-89].

5.5 Conclusions and recommendations

We first conclude that nutrient balances (NBs) in banana-coffee-based smallholder farming systems can be improved through the successful implementation of sustainable land use management practices. In successful households, the NBs are thoroughly positive. In less successful households, the NBs can be improved by utilising human urine, through the incorporation of herbaceous legumes, and via the production and application of biochar and sanitised human faeces in so-called CaSa-compost. However, under all scenarios, the same dependencies and constraints remain (labour-intensive manure collection and compost production, labour shortages, prolonged dry seasons, and socio-economic imbalances). As long as these constraints remain, nutrient deficiencies will not be overcome with mineral fertilisers alone.

As a second conclusion, we stress the importance of the system boundary. Only complete nutrient balances can give an estimation of the actual nutrient depletion and the resulting nutrient demand. Nutrient balances, however, must always take into account all removals, including those of fodder plants and trees or wood, and must not exclusively consider the nutrient gains from livestock manure as input; otherwise, this will always lead to an underestimation of nutrient removals. Thus, smallholder farmers in banana-coffee-based farming systems will always have to import fodder and wood to keep the nutrient balance neutral. The alternative is to reduce the number of livestock. Synthetic fertilisers could make up part of the nutrient deficit, but they must be used wisely, i.e., only on humus-rich soils, otherwise they would be too much of an economic burden on households and lead to further environmental damage.

Third, the observations made from this study raise the need to (i) study the current nutrient status of soil in depth (at least at a practical soil testing level), (ii) analyse the necessity of the coexistence of free-range livestock on grassland, and (iii) conduct an in-depth analysis of the socio-economic differences between successful and unsuccessful households. These further measures should be the next step in training at the Farmer field school MAVUNO Project. Farmer field schools also play a crucial role as multipliers of farm management knowledge and can serve as a best-practice example to be used in training and policy recommendations by government institutions to achieve the following SDGs in rural areas of East Africa: SDG 1 (no poverty), SDG 2 (zero hunger), SDG 6 (clean water and sanitation), SDG 7 (affordable and clean energy), and SDG 15 (life on land).

Author's contribution: This paper developed in the context of the PhD thesis of A.R. Conceptualisation, methodology, validation, and funding acquisition were carried out by the co-authors. Software and resources were provided by the Technische Universität Dresden and the United Nations University. Investigation, data curation, formal analysis and writing were mainly carried out by A.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Heinrich Boell Foundation and the United Nations University.

Acknowledgements: We acknowledge the cooperation with WOMEDA and MAVUNO Project (https://mavunoproject.or.tz/wp). We would also like to thank Claudia Matthias and Atiqah Fairuz Salleh for their support in visualization and Helen Grützner for editing. Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Conflict of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

5.6 Appendix A

Table 5-12: Literature data of the input (IN) and output (OUT) flows of nutrients, including nitrogen (N), phosphorus (P), and potassium (K) in different ecosystems or farming systems with a focus on African countries and tropical montane regions, except for coffee leaves. TDN refers to the total dissolved nitrogen. DM = dry matter, Nutr. = nutrient content.

Flow	Variable	Nutr.	Value	Unit	Source
IN1a	*Atmospheric deposition in smallholder mixed farming in Africa*				
		N	1.8	kg ha^{-1} yr^{-1}	[48]
		N	4.3	kg ha^{-1} yr^{-1}	[49]
		N	4.7	kg ha^{-1} yr^{-1}	[68]
		P	0.2	kg ha^{-1} yr^{-1}	[48]
		P	1.0	kg ha^{-1} yr^{-1}	[49]
		P	0.8	kg ha^{-1} yr^{-1}	[68]
		K	3.4	kg ha^{-1} yr^{-1}	[48]
		K	3.9	kg ha^{-1} yr^{-1}	[49]
		K	3.1	kg ha^{-1} yr^{-1}	[68]
	In montane tropical mixed forest, Congo	TDN	21.2	kg ha^{-1} yr^{-1}	[44]
IN1b	*Throughfall in montane tropical mixed forest*	TDN	42.1 ± 0.8	kg ha^{-1} yr^{-1}	[44]
IN2a	*Litterfall and deep capture*				
	Smallholder agroforestry with plantain and cacao	N	66.4	kg ha^{-1} yr^{-1}	[49]
	Smallholder agroforestry with plantain and cacao	P	5.15	kg ha^{-1} yr^{-1}	[49]
	Smallholder agroforestry with plantain and cacao	K	26.2	kg ha^{-1} yr^{-1}	[49]
	In montane tropical mixed forest	N	250 ± 20	kg ha^{-1} yr^{-1}	[44]
IN2b	*Deep capture from below the root zone*	N	16.6	kg ha^{-1} yr^{-1}	[49]
		P	1.38	kg ha^{-1} yr^{-1}	[49]
		K	6.55	kg ha^{-1} yr^{-1}	[49]
IN2c	*Biological fixation*				
	Beans (Phaseolus vulgaris)	N	19.0	kg ha^{-1} yr^{-1}	[48]
	Beans (Phaseolus vulgaris)	N	17-57	kg ha^{-1} yr^{-1}	[88]
	Beans (Phaseolus vulgaris)	N	8.0-58	kg ha^{-1} yr^{-1}	[51]
	Groundnut (Arachis hypogeae)	N	6.93	kg ha^{-1} yr^{-1}	[49]
	Permanent crops, cereals and oil crops	N	4.0	kg ha^{-1} yr^{-1}	[68]
	Pulses	N	18.0	kg ha^{-1} yr^{-1}	[68]
	Vegetables	N	8.0	kg ha^{-1} yr^{-1}	[68]
IN4a	*Crop residues of perennial crops after harvest*				
	Banana leaves (Musa AAA, Cavendish, cv. Rob.)	N	1.3	g plant^{-1}	[89]

Flow	Variable	Nutr.	Value	Unit	Source
	Banana leaves (Musa AAA, Cavendish, cv. Rob.)	P	0.2	g plant^{-1}	[89]
	Banana leaves (Musa AAA, Cavendish, cv. Rob.)	K	2.8	g plant^{-1}	[89]
	Banana leaves (Musa spp.)	N	2.0 - 2.5	%	[89]
	Banana leaves (Musa spp.)	N	4.4	% DM	[55]
	Banana leaves (Musa spp.)	P	0.15	% DM	[55]
	Banana leaves (Musa spp.)	K	1.0	% DM	[55]
	Banana leaves (Musa spp.)	N	2.75	% DM	[23]
	Banana leaves (Musa spp.)	P	0.1	% DM	[23]
	Banana leaves (Musa spp.)	K	4.85	% DM	[23]
	Banana leaves (Musa spp.)	N	25	kg ha^{-1} yr^{-1}	[23]
	Banana leaves (Musa spp.)	K	43	kg ha^{-1} yr^{-1}	[23]
	Banana leaves and stem (Musa spp.)	P	2.6	g kg^{-1} DM	[80]
	Plantain trunk (Musa spp.)	P	0.9	% DM	[80]
	Plantain trunk (Musa spp.)	K	40.8	% DM	[80]
	Banana pseudostems (Musa spp.)	N	3.0	kg ha^{-1} yr^{-1}	[23]
	Banana pseudostems (Musa spp.)	K	26	kg ha^{-1} yr^{-1}	[23]
	Banana pst. (Musa AAA, Cavendish, cv. Rob.)	N	0.7	g plant^{-1}	[89]
	Banana pst. (Musa AAA, Cavendish, cv. Rob.)	P	0.07	g plant^{-1}	[89]
	Banana pst. (Musa AAA, Cavendish, cv. Rob.)	K	4.2	g plant^{-1}	[89]
	Banana pseudostems (Musa spp.)	N	1.01	% DM	[23]
	Banana pseudostems (Musa spp.)	P	0.07	% DM	[23]
	Banana pseudostems (Musa spp.)	K	7.70	% DM	[23]
	Banana rhizome (Musa AAA, Cavendish cv. Rob.)	N	0.8	g plant^{-1}	[89]
	Banana rhizome (Musa AAA, Cavendish cv. Rob.)	P	0.07	g plant^{-1}	[89]
	Banana rhizome (Musa AAA, Cavendish cv. Rob.)	K	3.6	g plant^{-1}	[89]
	Coffee (Coffea arabica L.), leaves	P	1.2	g kg DM^{-1}	[80]
	Coffee (Coffea arabica L.), leaves	K	4.6	g kg DM^{-1}	[80]
	Coffee (Coffea arabica L.), hulls	N	2.01	%	[48]
	Coffee (Coffea arabica L.), hulls	P	0.20	%	[48]
	Coffee (Coffea arabica L.), hulls	K	2.77	%	[48]
	Coffee (Coffea arabica L.), hulls	P	1.4	g kg DM^{-1}	[80]
	Coffee (Coffea arabica L.), hulls	K	22.6	g kg DM^{-1}	[80]
	Mango (Mangifera indica L.), peels, dried	P	2.8	g kg DM^{-1}	[80]
	Mango (Mangifera indica L.), kernels, dried	P	2.8	g kg DM^{-1}	[80]
	Mango (Mangifera indica L.), kernels, dried	K	0.6	g kg DM^{-1}	[80]
IN4b	*Crop residues of annual crops*				
	Beans (Phaseolus vulgaris)	N	4.24	% DM	[48]
	Beans (Phaseolus vulgaris)	P	0.58	% DM	[48]
	Beans (Phaseolus vulgaris)	K	1.71	% DM	[48]
	Bean trash (Phaseolus vulgaris)	N	2.53	% DM	[23]
	Bean trash (Phaseolus vulgaris)	P	0.16	% DM	[23]
	Bean trash (Phaseolus vulgaris)	K	1.85	% DM	[23]
	Beans (Phaseolus vulgaris)	N	29	kg ha^{-1} yr^{-1}	[23]
	Beans (Phaseolus vulgaris)	K	21	kg ha^{-1} yr^{-1}	[23]
	Maize leaves, fresh (Zea mays L.)	P	1.5	g kg DM^{-1}	[80]
	Maize leaves, fresh (Zea mays L.)	K	16.6	g kg DM^{-1}	[80]

Flow	Variable	Nutr.	Value	Unit	Source
	Maize stover, fresh (Zea mays L.)	P	1.6	g kg DM^{-1}	[80]
	Maize stover, fresh (Zea mays L.)	K	16.8	g kg DM^{-1}	[80]
	Maize stover, dry (Zea mays L.)	N	0.58	% DM	[23]
	Maize stover, dry (Zea mays L.)	P	0.03	% DM	[23]
	Maize stover, dry (Zea mays L.)	K	2.67	% DM	[23]
	Maize stover, dry (Zea mays L.)	N	12	kg ha^{-1} yr^{-1}	[23]
	Maize stover, dry (Zea mays L.)	K	57	kg ha^{-1} yr^{-1}	[23]
	Maize stover, dry (Zea mays L.)	P	0.8	g kg DM^{-1}	[59]
	Maize stover, dry (Zea mays L.)	K	14.0	g kg DM^{-1}	[80]
	Cassava foliage, fresh (Manihot esculenta C.)	P	3.7	g kg DM^{-1}	[80]
	Cassava foliage, fresh (Manihot esculenta C.)	K	12.5	g kg DM^{-1}	[80]
	Cassava foliage, wilted (Manihot esculenta C.)	P	3.0	g kg DM^{-1}	[80]
IN4b	*Kitchen and food waste*				
	Banana peel (Musa, AAA-EAH)	N	1.14	% DM	[48]
	Banana peel (Musa, AAA-EAH)	P	0.12	% DM	[48]
	Banana peel (Musa, AAA-EAH)	K	4.99	% DM	[48]
	Banana peel (Musa spp.)	N	1.16	% DM	[23]
	Banana peel (Musa spp.)	P	0.64	% DM	[23]
	Banana peel (Musa spp.)	K	4.63	% DM	[23]
	Banana stalk (Musa, AAA-EAH)	N	0.92	% DM	[48]
	Banana stalk (Musa, AAA-EAH)	P	0.17	% DM	[48]
	Banana stalk (Musa, AAA-EAH)	K	8.33	% DM	[48]
	Banana stalk (Musa spp.)	P	2.9	g kg^{-1} DM^{-1}	[80]
	Banana stalk (Musa spp.)	K	53.5	g kg^{-1} DM^{-1}	[80]
	Cassava, peels, fresh (Manihot esculenta C.)	P	2.1	g kg DM^{-1}	[80]
	Cassava, peels, fresh (Manihot esculenta C.)	K	6.4	g kg DM^{-1}	[80]
	Cassava, peels, dry (Manihot esculenta C.)	P	0.8	g kg DM^{-1}	[80]
	Cassava, peels, dry (Manihot esculenta C.)	K	7.1	g kg DM^{-1}	[80]
	Maize cobs, without grain (Zea mays L.)	P	0.7	g kg DM^{-1}	[80]
	Maize cobs, without grain (Zea mays L.)	K	4.8	g kg DM^{-1}	[80]
IN4c	*Livestock manure*				
	Indigenous cattle, manure	N	14.9	g kg^{-1}	[48]
	Indigenous cattle, manure	P	3.45	g kg^{-1}	[48]
	Indigenous cattle, manure	K	12.39	g kg^{-1}	[48]
	Indigenous cattle, manure	N	1.49	%	[48]
	Indigenous cattle, manure	P	0.35	%	[48]
	Indigenous cattle, manure	K	1.24	%	[48]
	Improved cattle, manure	N	16.69	g kg^{-1}	[48]
	Improved cattle, manure	P	5.07	g kg^{-1}	[48]
	Improved cattle, manure	K	26.35	g kg^{-1}	[48]
	Improved cattle, manure	N	1.67	%	[48]
	Improved cattle, manure	P	0.51	%	[48]
	Improved cattle, manure	K	2.64	%	[48]
	Cattle manure	N	1.2	%	[58]
	Cattle manure	P	0.3	%	[58]
	Cattle manure	K	2.1	%	[58]
	Goat and sheep manure	N	1.5	%	[58]
	Goat and sheep manure	P	0.2	%	[58]
	Goat and sheep manure	K	3.0	%	[58]

Flow	Variable	Nutr.	Value	Unit	Source
	Goat manure	N	3.8	g kg^{-1}	[49]
	Goat manure	P	0.67	g kg^{-1}	[49]
	Goat manure	K	0.50	g kg^{-1}	[49]
	Sheep manure	N	3.2	g kg^{-1}	[49]
	Sheep manure	P	0.32	g kg^{-1}	[49]
	Sheep manure	K	0.40	g kg^{-1}	[49]
	Pig manure	N	2.5	g kg^{-1}	[49]
	Pig manure	P	0.48	g kg^{-1}	[49]
	Pig manure	K	0.65	g kg^{-1}	[49]
	Chicken manure	N	3.2	%	[58]
	Chicken manure	P	0.4	%	[58]
	Chicken manure	K	2.2	%	[58]
	Chicken manure	N	2.2	g kg^{-1}	[49]
	Chicken manure	P	0.37	g kg^{-1}	[49]
	Chicken manure	K	0.65	g kg^{-1}	[49]
	Bedding	N	6.14	g kg^{-1}	[48]
	Bedding	P	0.89	g kg^{-1}	[48]
	Bedding	K	7.03	g kg^{-1}	[48]
	Bedding	N	0.61	%	[48]
	Bedding	P	09	%	[48]
	Bedding	K	0.70	%	[48]
OUT1a	*Harvest of perennial crops*				
	Banana pulp (Musa, AAA-EAH)	N	0.71	% DW	[48]
	Banana pulp (Musa, AAA-EAH)	P	0.11	% DW	[48]
	Banana pulp (Musa, AAA-EAH)	K	0.49	% DW	[48]
	Coffee beans (Coffea robusta)	N	2.28	% FW	[48]
	Coffee beans (Coffea robusta)	P	0.23	% FW	[48]
	Coffee beans (Coffea robusta)	K	2.26	% FW	[48]
	Coffee (Coffea arabica L.), pulp, without seeds	P	1.3	g kg DM^{-1}	[80]
	Mango (Mangifera indica L.) fruits, fresh	P	1.0	g kg DM^{-1}	[80]
	Mango (Mangifera indica L.) fruits, fresh	K	7.7	g kg DM^{-1}	[80]
	Mango (Mangifera indica L.), pulp, fresh	P	1.1	g kg DM^{-1}	[80]
	Mango (Mangifera indica L.), pulp, fresh	K	13.3	g kg DM^{-1}	[80]
OUT1b	*Harvest of annual crops*				
	Beans (Phaseolus vulgaris)	N	4.24	% DW	[48]
	Beans (Phaseolus vulgaris)	P	0.58	% DW	[48]
	Beans (Phaseolus vulgaris)	K	1.71	% DW	[48]
	Maize grain (Zea mays L.)	N	3.0	g kg DM^{-1}	[80]
	Maize grain (Zea mays L.)	P	2.9	g kg DM^{-1}	[80]
	Maize grain (Zea mays L.)	K	3.6	g kg DM^{-1}	[80]
	Cassava tubers, fresh (Manihot esculenta C.)	P	1.2	g kg DM^{-1}	[80]
	Cassava tubers, fresh (Manihot esculenta C.)	K	7.7	g kg DM^{-1}	[80]
	Cassava tubers, fresh, peeled (Manihot esculenta C.)	P	0.4	g kg DM^{-1}	[80]
	Cassava tubers, dehydrated (Manihot esculenta C.)	P	1.1	g kg DM^{-}	[80]
	Cassava tubers, dehydrated (Manihot esculenta C.)	K	9.9	g kg DM^{-1}	[80]
	Tubers (cassava)	N	0.56	% FW	[48]
	Tubers (cassava)	P	0.18	% FW	[48]
	Tubers (cassava)	K	1.22	% FW	[48]
OUT6	*Leaching*				

Flow	Variable	Nutr.	Value	Unit	Source
	Leaching below the root zone	N	6.0	kg ha^{-1} yr^{-1}	[48]
	Leaching below the root zone	P	0	kg ha^{-1} yr^{-1}	[48]
	Leaching below the root zone	K	11.0	kg ha^{-1} yr^{-1}	[48]
	Leaching below the root zone	N	26.4	kg ha^{-1} yr^{-1}	[49]
	Leaching below the root zone	K	0.88	kg ha^{-1} yr^{-1}	[49]
	Leaching at 20 cm depth	TDN	27.7 ± 17.7	kg ha^{-1} yr^{-1}	[44]
	Leaching at 40 cm depth	TDN	17.3 ± 16.6	kg ha^{-1} yr^{-1}	[44]
	Leaching at 80 cm depth	TDN	15.5 ± 9.7	kg ha^{-1} yr^{-1}	[44]
OUT9	*Gaseous loss*				
	Emission from soil	N	6.34	kg ha^{-1} yr^{-1}	[49]
	Emission from soil	N_2O	3.45	kg ha^{-1} yr^{-1}	[44]
	Emission from burning natural vegetation	N	47.8	kg ha^{-1} yr^{-1}	[49]
	Emission from burning natural vegetation	P	1.8	kg ha^{-1} yr^{-1}	[49]
	Emission from burning natural vegetation	K	14.2	kg ha^{-1} yr^{-1}	[49]
	Emission from denitrification	N	20	kg ha^{-1} yr^{-1}	[48]
	Release of NH_3, NO, N_2O, N_2, cereals	N	5.6	kg ha^{-1} yr^{-1}	[68]
	Release of NH_3, NO, N_2O, N_2, pulses	N	3.3	kg ha^{-1} yr^{-1}	[68]
	Release of NH_3, NO, N_2O, N_2, banana, coffee	N	15.2	kg ha^{-1} yr^{-1}	[68]
	Release of NH_3, NO, N_2O, N_2, vegetables	N	21.3	kg ha^{-1} yr^{-1}	[68]

DW = dry weight. DM = dry matter. cv. = cultivar. pst. = pseudostem. Rob. = Robusta. [23] refers to smallholder banana-based farming systems in Uganda; [44] to tropical montane mixed forest in Congo basin; [48] to banana-coffee-based farming, Karagwe, Kagera region in Tanzania; [49] to smallholder mixed farming in Cameroon; [51] to worldwide study on nitrogen-fixing crop legumes; [54] in data collection of feeding recommendations in tropical and Mediterranean regions; [80] to laboratory experiments in basic research; [59] in review of manure samples from kraals and animal sheds in Eastern and Southern Africa; [69] in smallholder mixed farming, Ethiopia; [89] in field trial in horticulture research in Bangalore; and [90] to banana production in Hawaii.

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6 Synthesis

6.1 Summary and discussion of the results

6.1.1 The status quo of organic farm waste management

The first research question (chapter 1.4.1) calls for the description and categorisation of the *status quo* of organic farm waste management and its integration into degraded banana-coffee-based farming systems. The description of current farm waste uses, their influence on crop yields, and the potential introduction of human excreta in organic farm waste management have been described in depth in Reetsch *et al.* (2020a; chapter 2) and compared to composting strategies in the Morogo region in central Tanzania in Reetsch *et al.* (2020d; chapter 3). The corresponding data set have been published in Reetsch *et al.* (2020c; 2021a; appendix from page 233 onwards). This chapter summarises those findings.

Categorisation of farm households

The East African Highland Banana (EAHB-AAA) and other banana cultivars (*Musa* L. spp.), coffee (*Coffea canephora* L. var. *robusta*), beans (*Phaseolus vulgaris* L. and other spp.), and maize (*Zea mays* L. and other spp.) have remained the most important crops for food supply and economic profit generation in the study area. These crops are cultivated in the homegardens of banana-coffee-based farming systems. The results of the household survey reveal that smallholder farm households can be categorised into three groups according to their agricultural production and socio-economic conditions. They significantly differ in terms of land size, crop yields, livestock-keeping, agricultural diversity, available labour, market access, food security, wealth, and gender-based distribution of labour, decisions, and responsibilities. The groups are named from A to C, with the suffix $_U$ meaning 'untrained'. Households are wealthiest in Group A_U, while households in Group B_U range from moderately wealthy to poor, and those in Group C_U are poorest and most affected by high food insecurity. None of these households are food secure. Even Group A_U households lack constant food availability throughout the year. Farm households belonging to Groups A_U and B_U have a relatively high potential to increase their biomass production and to become food secure, while yields in Group C_U remain far below the potential crop yield. Besides, none of the households will be energy secure while they still have to access the forest to find firewood, and do not use an efficient cooking stove. Only those households whose homegardens happen to be located alongside main roads are connected to the national electricity grid.

It is important to emphasise that the gender distribution among the household groups varies according to their wealth status. These variations affect the available labour within a family and make it more difficult to escape the poverty trap. In Group A_U, family size is relatively huge (10.2 ± 7.09) with a low age-dependency ratio (1.00 ± 0.94) and families are often headed by married men. In contrast, in Group C_U, families are smaller (5.72 ± 2.37), have a higher age-dependency ratio (2.03 ± 1.78), and are often led by single women. Group C_U households are more impoverished and are unlikely to escape the poverty trap while they still have to sell their labour to the wealthier families. Working for other households means less time to maintain agricultural production on their own tiny homegardens; therefore, yields steadily decrease, and with them the prospect of food security. For these households, the introduction of labour-intensive composting and mulching methods will not be a priority while they are struggling to survive.

Description of farm waste management techniques

The integration of organic farm waste into biomass production has continued to be an integral part of farming practice. Farm waste is mainly collected, treated, and applied to soils in the homegardens of the banana-coffee-based farming systems. That is why the following findings and their discussion concentrate on the homegardens. In the homegardens, smallholder farming families apply three forms of organic farm waste management techniques. The techniques involve the collection of organic farm waste, a treatment phase and, in some cases, a distribution phase. Organic farm waste is either collected in holes (pits or ring-holes) or systematically spread on the ground and piled only a few centimetres high (*in situ*). Accordingly, these techniques are called pit, ring-hole and *in situ* composting (Fig. 2-4 at page 63). They have been identified as traditional.

In pit composting, a pit is mainly filled with kitchen and food waste, and only occasionally with livestock manure for reasons of hygiene, due to its proximity to the kitchen and food processing area. *In situ* composting has a mulching effect because crop residues and leaves from banana plants and trees, as well as occasionally kitchen and food waste, are collected and carefully spread over the soil. Through this cover, the topsoil is protected from splash, sheet and gully erosion caused by heavy rainfalls. It is also protected against wind erosion and soil drying, and water infiltration is enhanced. The collected organic material decomposes on-site as part of the composting process. In ring-hole composting, a ring-hole is dug directly around perennial plants, mainly banana plants and coffee shrubs. It is primarily filled with livestock manure, followed by kitchen waste. Pit composting is the only one of these three methods in which the pit is re-opened; this occurs after several weeks, and the rotten material, also called ‘compost’ or ‘organic fertiliser’, is distributed onto the fields.

In contrast to this tradition, as described by Copeland Reining (1967), Katoke (1970), and Touber and Kanani (1996), the results reveal that most farmers use more than one of these traditional composting techniques. If the techniques are not separated according to their traditional use, e.g., ring-hole composting only for coffee and banana plants, or pit composting only for vegetables, the term mixed composting has been introduced in this research. Besides, not all households produce or use all types of organic waste.

The influence of farm waste management on crop yields

The findings clearly show that smallholder farmers who apply composted organic farm waste, also called 'compost' according to the definition used by Diaz *et al.* (2007), to their fields have higher yields. Considering biomass production, Group A_U produces relatively high, Group B_U moderate, and Group C_U low amounts of organic farm waste and compost. Farm households that apply compost as organic fertiliser and soil conditioner to their fields have higher crop yields. This is the case for most households in Group A_U, and this tendency decreases to almost nothing in Group C_U.

However, the potential of organic fertiliser to improve yields has not been fully realised for five reasons. First, farmers do not make use of all the different types of organic farm waste. Second, knowledge of traditional organic waste management has been limited due to the impact of the HIV/AIDS pandemic. Third, other survival needs and tasks take priority over farm waste management. Fourth, soils are rarely allowed to rest. Farmers omit fallow periods and the cultivation of cover crops due to land scarcity. Fifth, the quantity of organic fertiliser is insufficient to counteract soil nutrient depletion in the long term.

Modification: Willingness to use human excreta as fertiliser

Two-thirds of the surveyed farmers refused to use human excreta-derived fertiliser for hygienic reasons when they were asked the first time. After introducing the CaSa-compost techniques to them (*cf.* Krause *et al.* 2015), only two farmers out of 150 suspected that its application would not have a positive impact on soil fertility. Farmers would generally apply it to their fields if they had the relevant knowledge and were confident in implementing it. They have directly asked for the opportunity to be trained in its application. It is particularly important to them that it does not cause any health problems or ecological damage.

Gwara *et al.* (2020) and Okem and Odindo (2020) have also shown that farmers would accept human excreta-derived fertiliser if they had safe guidelines. Farmers rightly insist that its use should be risk-free. Contamination of soils with helminth eggs caused by parasitic worms in human faeces endanger horticulture and agriculture in areas where sanitation is poor or where untreated human faeces is used as soil fertiliser (Moya *et al.* 2019; WHO 2020). Open defecation is banned in most countries around the world, including Tanzania. However, the use of fertiliser derived from human excreta is often unregulated, although it is a common practice in rural, impoverished areas (*cf.* Jensen *et al.* 2008). Clear guidelines for its risk-free use are often lacking (*cf.* Moya *et al.* 2019).

Even if not all hygienic risks have yet been overcome, scientists and engineers have already made progress in the technical processing of faeces to enable its safer use as fertiliser. Thereby, the prevalence of *Escherichia coli* (abbreviated *E. coli*), a pathogenic bacterium found in animal and human intestines, is often used as an indicator of faecal contamination of soils and water bodies (*cf.* Krause 2017). However, this baseline indicator is not always analysed, and it is not the only worrisome bacterium. Irrigation with water contaminated with *E. coli* and *Salmonella* spp. are restricted by the WHO (2011, 2020). Effebi *et al.* (2019) have found various bacteria including total coliforms, faecal coliforms, and faecal streptococci, along with *Ascaris lombricoïds* in faeces-based compost. Schneeberger *et al.* (2019) have extensively investigated the exact concentration of diverse bacteria in wastewater-contaminated wetlands near Kampala, Uganda under similar climatic and geomorphological conditions as in the study area. They call *the prevalence of a set of known waterborne bacterial pathogens throughout the Nakivubo [wetland] system the 'pathobiome'* (*ibid.*).

Comparison to other regions in Tanzania

For comparison, a farmer field school established by the Sokoine University of Agriculture in the Uluguru Mountains, in the Morogoro region in central Tanzania, aims to educate smallholder farmers on the impact of conservation tillage and plant nutrient status (Kimaro *et al.* 2011). Both regions, the Kagera and the Morogoro region, suffer from land degradation caused by human activities and climate change. The farmers in the Uluguru Mountains are trained in how to increase the productivity of their farming systems through composting. This includes the application of *in-situ* and on-surface composting (*cf.* Fig. 3-7 at page 101) in combination with conservation tillage and terracing. The results showed that yields under *in-situ* composting and conservation tillage are significantly higher than under conservation tillage and livestock manure alone, traditional terrace and manure alone, controlled conservation tillage, and controlled traditional terrace, due to improved soil fertility and decreased soil losses (*ibid*). The FFS has concluded that integrating composting practices into conservation tillage for crop production on sloping land is the best practice for sustainable crop production, nutrient availability, and reduction of soil loss (*ibid*).

As a second example, soil and land degradation in the banana-coffee-based farming systems of the Kilimanjaro region have been successfully counteracted by composting for several decades (Hemp and Hemp 2008; Kimaro *et al.* 2011). There, biodiversity has been highly maintained with a dense vegetation structure consisting of four layers. Thus, this agroforestry system has remained multifunctional by producing food, biofuels, cash crops, and medicine. Degraded homegardens, as in the Kagera region, are less densely cropped, have fewer plant species, and consist of only one or two, or occasionally three vegetation layers. Multi-layered homegardens in the Kilimanjaro region can be understood as a target state for degraded banana-coffee-based farming systems in the Kagera region. This target state could be achieved through composting.

6.1.2 The modification of traditional farm waste management

The second research question (chapter 1.4.2) delves into the improvement of agricultural productivity in degraded banana-coffee-based farming systems. The achievements of the local farmer field school (FFS) MAVUNO Project have therefore been investigated in detail. The FFS has trained 755 smallholder farm households in sustainable land-use management (SLM). The SLM training focuses on the restoration of degraded homegardens into dense, multi-layered, and multifunctional agroforestry systems (*cf.* Fig. 4-1 at page 115). The findings have been reviewed in the form of a journal article in Reetsch *et al.* (2021b), and compared to fertile banana-coffee-based farming systems in the Kilimanjaro region in NE Tanzania. This chapter summarises those findings.

Categorisation and differentiation

The results have revealed three groups of trained smallholder farm households, which are named Group A_T, B_T and C_T ('T' meaning 'trained'). Households in Group A_T have implemented all of their training, those in Group B_T have implemented around half of it, and those in Group C_T have implemented an insufficient amount. Farmers in Group A_T are self-motivated to change their behaviour and traditions, if this is to their benefit, follow the instructions of the trainers, search for advice in challenging situations, and cultivate a high diversity of crops and trees. They have implemented zero-grazing, and are regarded as high-income earners (1,363 UDS yr^{-1}, Table 4-1), who meet their families' needs at any time of the year. They are food secure. Households in Group B_T have started to integrate advanced fertility and pesticide management, and are classified as middle-income earners (590 USD yr^{-1}), covering their basic needs at almost any time of the year, and seeking to develop further. However, they have not enough food throughout the year. In contrast, farmers in Group C_T belong to the low-income earner category (230 USD yr^{-1}), are often unable to cover their basic needs, and are not developing towards the level of Group B_T. These households are below the poverty line of $ 1.90

(*cf.* World Bank 2015). They are often households with single parents, many children (high age-dependency ratio), small farm size, and/or sick family members.

In summary, the situation has considerably improved for 40% of the trained farm households (Group A_T), and considerably improved for 35% (Group B_T). The remaining 25% of the trained households (Group C_T) remain vulnerable to food and energy insecurity. As some trainers committed in the individual interviews, increased alcohol consumption, frustration, failure in the labour market, lack of participation in education, and poor connection to the community have probably also led to this failure.

The findings show essential differences between the trained and untrained farm households. Those who successfully implemented the SLM training have reached a higher level of agricultural productivity and multifunctionality, biodiversity, prosperity, and access to education. Multifunctionality of their homegardens is achieved by producing food, fodder, timber, and biofuel for consumption and sale; by providing soil- and water-related ecosystem services; and by adapting to climate change. Farm waste management practices can be improved through the distribution of rotten organic farm waste, by minimising the volatilisation and leakage of farm waste, and via the application of the advanced composting techniques known as 'trench composting' (Figures 4-6 and 4-7 at page 131). In trench composting, a trench with a depth of 50 to 60 cm is dug parallel to the contour lines of the hills, and added with organic waste material (i.e., crop residues, kitchen waste, ashes, and livestock manure). During the composting process, the rotting material is turned over at least once a month. Full compost trenches are covered with earth, and rotten material is added to the soil after two to four months.

Another issue that is important to highlight is the integration of gender-inclusive communication and decision-making as a key skill for the successful implementation of the training. Those households that have successfully integrated gender-inclusive communication and decision-making have become food secure.

Transition process and remaining challenges

The transition process, from degraded to productive multifunctional farming systems, takes many years. It requires constant monitoring, advice, and adaptation of the training content to practise. The initial situation of the farmers participating in the training is decisive in determining how long this process takes. If, for example, households from Group A_U were to start the training, they would probably manage its subsequent implementation more easily than farmers from Group B_U. Farm households from Group C_U would probably be more likely to fail if they only received the training and no additional support to help them free themselves from the chains of poverty.

Even for successful households, some challenges and bottlenecks remain. The farmers still face challenges in a) safely integrating human excreta into their farm waste management, and b) generating more sustainable energy sources, as well as improving the energy efficiency in the use phase. The trainers highly recommend producing CaSa-compost as organic fertiliser (chapter 4.2.2), which means installing urine-diverting dry toilets (UDDTs). However, they emphasise the high cost of the UDDTs and of the equipment for sanitising human urine and faeces. In addition, the sanitation phase is currently still questionable as regards the health of the farmers. The separately collected faeces are transported in buckets to a clay oven specially built for this purpose, where they are decanted and heated (*cf.* Krause and Rotter 2018). Before treatment, there is a high risk of contamination. After heating according to the suggested procedure (*cf.* Krause and Rotter 2018), the faeces should be free of bacteria, worm eggs and other pathogens. The additional labour is also a challenge for the farmers. Also, this process needs additional fuel, which is difficult for some households, as this resource is already limited.

The remaining challenges relate to the high cost of producing CaSa-compost, the lack of knowledge concerning the level of nutrients to be added to the soils, the quantity of inputs available, the scale of application, and social acceptance of using human excreta as fertiliser. Although the CaSa-compost would be useful to all three groups of households, only a few farmers in Group A_T might be able to finance a UDDT, and it would not be an option for the farmers from Groups B_T and C_T. The trainers emphasise the need to take soil samples before adding any fertiliser. Farmers do not know the actual soil fertility status of their fields because they cannot afford soil sampling. They can only estimate the conditions of their soils by observation. Besides, the trainers are unsure whether the necessary organic materials would be accessible at all farms all year round. Thus, they have varying opinions on the likely level of implementation: either at the family level, or at a broader institutional level, e.g., schools, hospitals, churches, and prisons. To save labour, they suggested implementing the concept first in schools, where people are paid to empty pit latrines anyway. If this is to be successful, communities need to be made aware of the benefits of using human excreta; it needs to be rendered acceptable to them.

Regarding energy, even trained farm households have not yet become energy secure. In all groups of households, firewood and charcoal have remained as the primary sources of energy. To reduce the amount of firewood and charcoal required, a limited number of households in Group A_T (below 10%) bought improved cooking stoves, e.g., solar cooking stoves and microgasifers, and some households built biogas plants (below 2%). The feedstocks for the biogas plants are crop residues and livestock manure. In Group B_T, households mainly use firewood for cooking, and a few families own improved cooking stoves and biogas plants, whereas in Group C_T, farmers only cook with firewood on 3-stone stoves. Another relevant point here is that houses along main roads are more likely to be connected to the national electricity grid than those along small trails.

6.1.3 The optimisation of farm waste management

The third research question (chapter 1.4.3) calls for the optimisation of existing farm waste management practices in the study area. In this analysis, the nutrient balances of biomass and organic farm waste in the homegardens of untrained and trained farm households have been further investigated. In addition, the potential of composting to compensate for nutrient deficiencies has been analysed, scenarios for optimal waste use have been developed, and favourable ecological and socio-economic conditions have been considered for their feasibility. The results have been published in the journal article Reetsch *et al.* (2020b; chapter 5).

Inventory

First, the nutrient balances (NBs) of nitrogen (N), phosphorus (P), and potassium (K) were analysed for the homegardens of both, untrained and trained farm households. These balances were recorded as each household's baseline scenario, defined as S0, 'business as usual'. The following inflows (INs) were considered: atmospheric deposition, above-ground and below-ground inputs by plants and trees, biological fixation, and organic fertiliser consisting of crop residues, kitchen and food waste, cooking ash, and livestock manure and urine. The following were taken into account as outflows (OUTs): harvested crops, fodder, wood (used both as timber and for firewood), sold crops and crop residues, leaching from soil in general and from pit latrines in particular, river discharge, and gaseous losses. Nutrient stocks, for the purposes of this study, were the human and animal body, and the pit latrine.

It was found that the NBs in trained farm households were more positive than in untrained ones (*cf.* Figures 5-3 and 5-4 at pages 182 and 183). In the 'business as usual' scenarios, the NBs of N and P are negative for all untrained groups of households and for Group C_T, ranging from -82 to -56 kg N and -5 to -1 kg P ha^{-1} yr^{-1}. In the same groups, K ranged from 5 to 47 kg K ha^{-1} yr^{-1}. In general, NBs are highly dependent on many variables, i.e., on crop and fodder production and the resulting waste materials, the decomposition rate of organic materials, amendments to organic fertiliser, soil management, mulching, available mineral nitrogen and non-available nitrogen in the soil and soil water, gaseous losses, plant density, harvest time, irrigation in the driest months, exposure to sunlight, length of the dry season, the weather, and the climate (Andersson 2015; Dakora and Keya 1997; Guzha *et al*. 2005; Hegde and Srinivas 1989; Krause *et al*. 2016; Krause and Rotter 2018; Ndabamenye *et al*. 2013; Richert *et al*. 2010).

Potential of organic farm waste

Currently, nutrient cycles in the successfully trained farm households Group A_T and B_T can potentially be closed. Here, nutrient balances range from 12 to 97 N kg, from 9 to 24 kg P, and from 131 to 260 kg K ha^{-1} yr^{-1}. However, these results have two limitations. First, the soil is not considered as a nutrient stock in this analysis. Unless the current nutrient status of the soil is measured and interpolated for each homegarden, it is hard to guarantee that nutrient cycles will be closed. Soils with high soil nutrient depletion take longer to recover than soils with lower nutrient depletion. Second, these households strongly depend on nutrient inputs from outside, in particular from the grassland. Besides, overgrazing of the grassland has not yet diminished. It can be assumed that the amount of organic fertiliser that one homegarden can produce is not sufficient on its own to counteract soil nutrient depletion in the long term. Farmers need a more advanced, holistic solution.

Scenarios

The following four scenarios have been analysed and compared to the 'business as usual' scenarios: S1, the application of human urine, S2, the fostering of leguminous plants, S3, the production of CaSa-compost, and S4, which is a combination of S1, S2, and S3. The NBs increase with the scenarios in the following order: S4 > S3 > S1 > S2. Phosphorus contents increase considerably with the application of CaSa-compost in all groups of households. The untrained households in Groups A_U and B_U would especially benefit from S4.

Beneficial conditions

Whether it is the implementation of the SLM training and/or the realisation of one of the scenarios, both of these 'optimisation packages' should be accompanied by low-tech, labour-reducing measures. The measures and technologies should be free of any health risk. The treatment phase of human excreta in particular needs to be improved. In any case, human excreta should not remain unused as a nutrient resource and continue to enter groundwater and receiving waters through leaky pit latrines. As a consequence, faecal matter enters the Lake Victoria via the Kagera River basin. Besides, salinisation of soils from human urine application needs also to be monitored (*cf.* Andersson 2015).

Although the production of biochar is part of the production process of the CaSa-compost, it could be also considered as a measure to improve soil properties independently of the use of human excreta without producing compost. Biochar is carbonised organic matter (OM) that is produced during the slow combustion (pyrolysis) of plant-derived feedstock, e.g., sawdust (Krause *et al*. 2015, 2016). Biochar is rich in carbon and its mean residence time is several hundred to thousands of years, which makes the use of biochar attractive as a long-term soil amendment because of its fertilising and liming effects and for carbon sequestration (Agegnehu *et al.* 2016; Lorenz and Lal 2018). Therefore, its integration into sustainable tropical agroforestry systems is promising for sequestering large amounts of carbon in the long term, increasing agronomic productivity, and supporting a range of ecosystem services (Stavi and Lal 2013; Verheijen *et al.* 2014, 2017). The positive effect could be further enhanced by using biochar in the production of compost (*cf.* Agegnehu *et al.* 2016; Krause *et al*. 2016). On the other hand, the addition of biochar to nutrient-rich soils, such as many temperate soils, can have the opposite effect, and bind nutrients in such a way that they are no longer available to the plants (Ngo *et al*. 2016). However, its characteristics vary as feedstocks vary and may be restricted to the tropics, where arable soils typically have a low pH and low fertiliser inputs (Lorenz and Lal 2018). Here, farmers may receive payments for mitigating climate change and sustaining food security (*cf*. Stavi and Lal 2013).

To close the nutrient gap, the combination of organic and mineral fertiliser should be further considered. Organic waste management and mineral fertiliser can bring added benefits to soils and plants. For instance, organic matter on the soil surface prevents the soil drying out in the dry seasons of the year, while the application of mineral fertiliser provides the plants with nutrients (*cf.* Vanlauwe 2015). The accumulation of soil OM and humus promotes nutrient storage in soils. However, caution is required here. If mineral fertilisers are not applied correctly in terms of quantity, time, and place, they can increase environmental degradation, e.g., through groundwater pollution. The safe use of mineral fertiliser, meaning the selective, plant-specific, well-dosed, and carefully timed application of mineral fertiliser to humus-enriched soils – humus is first needed to store nutrients in a plant-available form and to avoid the leakage of nutrients into water bodies – could balance the nutrient shortage in the short term (*cf.* Vanlauwe and Giller 2006; Vanlauwe *et al.* 2017). However, only half of the untrained farmers think that mineral fertiliser would improve their soils, though slightly more than half would wish to have access to mineral fertiliser in order to try it out.

6.2 Relevance to the Sustainable Development Goals (SDGs)

None of the untrained smallholder households lives under the conditions that the SDGs are intended to prescribe. Trained farming households that have successfully transformed their degraded homegardens into multifunctional land-use systems, or are in the process of doing so, are one step closer to achieving the SDG targets.

For the farming families in the study area, the following SDGs are central within the scope of this research project:

Goal 2: Zero hunger – End hunger, achieve food security and improved nutrition and promote sustainable agriculture

2.1 By 2030, end hunger and ensure access by all people […] to safe, nutritious, and sufficient food all year round.

2.3 By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, family farmers […], knowledge, financial services, markets and opportunities for value addition and non-farm employment.

2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change […] and that progressively improve land and soil quality.

2.5 By 2030, maintain the genetic diversity of seeds, cultivated plants, and farmed and domesticated animals and their related wild species, including through soundly managed and diversified seed and plant banks […].

Goal 7: Affordable and clean energy – Ensure access to affordable, reliable, sustainable, and modern energy for all

7.1 By 2030, ensure universal access to affordable, reliable […] energy services.

7.3 By 2030, double the global rate of improvement in energy efficiency.

Goal 15: Life on land – Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

15.1 By 2030, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements.

15.2 By 2030, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally.

15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought, and floods, and strive to achieve a land degradation-neutral world.

15.4 By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development.

15.6 Promote fair and equitable sharing of the benefits arising from the utilization of genetic resources and promote appropriate access to such resources, as internationally agreed.

15.9 By 2030, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts.

The findings of the thesis reveal that the following SDG targets are also relevant in the context of this research, although they were not part of its focus initially:

Goal 1: No poverty – End poverty in all its forms everywhere

1.1 By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day.

1.4 By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights to economic resources, access to basic services, ownership and control over land and other forms of property, natural resources, appropriate new technology and financial services […].

Goal 3: Good health and well-being – Ensure healthy lives and promote well-being for all at all ages

3.3 By 2030, end the epidemics of AIDS, tuberculosis, malaria and neglected tropical diseases and combat hepatitis, water-borne diseases, and other communicable diseases.

3.5 Strengthen the prevention and treatment of substance abuse, including narcotic drug abuse and harmful use of alcohol.

Goal 4: Quality education – Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

4.1 By 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes.

4.3 By 2030, ensure equal access for all women and men to affordable and quality technical, vocational, and tertiary education, including university.

4.6 By 2030, ensure that all youth and a substantial proportion of adults, both men and women, achieve literacy and numeracy.

Goal 5: Gender equality – Achieve gender equality, empower all women and girls

5.4 Recognize and value unpaid care and domestic work through the provision of public services, infrastructure and social protection policies and the promotion of shared responsibility within the household and the family as nationally appropriate.

5.5 Ensure women's full and effective participation and equal opportunities for leadership at all levels of decision-making in political, economic, and public life.

Goal 6: Clean water and sanitation – Ensure availability and sustainable management of water and sanitation for all

6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all.

6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.

6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes.

Goal 13: Climate action – Take urgent action to combat climate change and its impacts

13.1 Strengthen resilience and adaptive capacity to climate-related hazards […].

13.2 Integrate climate change measures into national policies […].

13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction […].

For the sake of completeness, out of the scope of this thesis are Goal 8: Decent work and economic growth; Goal 9: Industry, innovation, and infrastructure; Goal 10: Reduce inequality within and among countries; Goal 11: Sustainable cities and communities; Goal 12: Responsible consumption and production; Goal 14: Life below water; Goal 16: Peace, justice, and strong institutions; and Goal 17: Partnership for the Goals.

6.3 Outline of a roadmap for the implementation of the SDG target 2.4

As Breuer *et al.* (2019) vividly pointed out, the interlinkages and interdependencies of the SDGs are complex. To understand and deal with this complexity, a number of concepts for the systematic conceptualisation of the SDGs have been reviewed by Breuer *et al.* (2019). The authors categorise the most common approaches as follows:

a) clustering the SDGs according to their systemic function, often with an anthropocentric nature, as in Hoff (2018) and Raworth (2017), based on the planetary boundaries developed by Rockstrom *et al.* in 2009;

b) focusing on the target-level interlinkages between the SDGs based on the wording of the targets, e.g., Le Blanc (2015);

c) following the priorities for policy action in implementing the SDGs, e.g., Scott *et al.* (2017); and

d) an applied empirical analysis of synergies and trade-offs between the SDGs by using mathematical equations or simulation models, e.g., after Griggs *et al.* (2014), ICSU (2017), or Weitz *et al.* (2018).

Each approach has its advantages and limits, and the complexity of choice is almost infinite. As Breuer *et al.* (2019) recommend in conclusion, *the focus should be less on illuminating the complexities of interlinkages and interdependencies and more on prioritising key targets and translating them step by step into policy action*. In order to make the implementation of the SDGs easier to digest, the authors propose the following 5-step roadmap (*ibid*.).

An attempt of a 5-step roadmap following Breuer et al. (2019), applied to the research findings of this thesis, using SDG target 2.4 (sustainable food production systems) as an example:

1

Problem identification: The degradation of vegetation and soil resources remains high in previously very fertile and productive regions, e.g., the Kagera region. The local population, in particular female-led farm households, remain the most vulnerable to food insecurity. The provision of the urban population with food is not secure. Ecosystem services have decreased. National exports of bananas and coffee are at risk.

Entry point: SDG target 2.4 by 2030, ensure sustainable food production systems and implement resilient agricultural practices including seed production and trade that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, and that progressively improve land and soil quality.

Geographical area: The Kagera region in NW Tanzania. The approach could be improved by benchmarking the planetary boundaries for the study area following Hoff (2018) and Rockstrom *et al.* (2009).

2

Inputs: Organic farm waste, soil, water, smallholder agriculture, and others.

Stakeholders: Smallholder farming families, the local farmer field school MAVUNO Project and the non-profit organisation WOMEDA, village officers, local government in Karagwe and Bukoba, and others.

External risks and uncertainties: Severe environmental degradation, rural depopulation, decreasing exports, and others.

3

Interdependencies: Analysing the interdependencies within bounded landscapes following Nilsson *et al.* (2016) and Reed *et al.* (2016), reducing their complexity by focusing on delineated spatial units and their socio-economic and environmental conditions. *Synergies* and *trade-offs* are clear.

4

Critical reflection and discussion of the identified synergies and trade-offs and the temporal urgency to achieve the goal. Ethically justifiable decisions are made on the prioritisation of political actions in light of the respective societal background.

5

Formulating policy recommendations based on the previous four steps, advancing possible and necessary institutional reforms to achieve better-integrated policy-making and to advance necessary science-based approaches towards SDG implementation.

This attempt could be a start for future initiatives to analyse and develop a coherent policy for the implementation of the SDG target 2.4, e. g., at the Ministry of Agriculture and the National Land Use Planning Commission (NLUPC) of The United Republic of Tanzania. Further topics could focus on the promotion of the safe use of organic waste, human excreta-derived fertiliser, and wastewater in smallholder agriculture. The necessity is immediate as plant nutrients are urgently needed, soil degradation needs to be stopped and soils restored, and the application of mineral fertiliser is often too expensive and, in most cases, not affordable for the farmers.

National regulations for the safe use of human excreta-derived fertiliser, other organic waste materials and wastewater in smallholder agriculture and urban gardening are often lacking, as is the case in Tanzania. To develop science-based guidelines, the promotion of research programmes is required, e.g., by allocating research permits to international research institutions, with the obligation to share the research results with the government and to develop appropriate policy recommendations (science-policy transfer). Stakeholders may develop the norms, guidelines, regulations, policies, laws, and institutions that are needed to realise the desired scenario within the framework of the SDGs. Supporting factors could be:

a) the development of composting regulations, perhaps similar to the Biowaste Regulations (BioAbfV[1]) in Germany,

b) the safe use of human urine for the production of food and cash crops, e.g., as recommended by Andersson (2015), and

c) integrating lessons learned from local best-practice examples, e.g., the successful implementation of the training on sustainable land-use management by the farmer field school MAVUNO Project. Limiting factors would need to be addressed, such as limited labour, limited land size, limited knowledge, and a lack of adaptation to and mitigation of climate change.

Adapted to this study, the following three scenarios could be expanded further:

Scenario 1: The optimum. Precisely adapted and optimised composting techniques enable safe use of human excreta-derived fertiliser in smallholder banana-coffee-based farming systems in the Kagera region and other regions with similar conditions. Thus, valuable plant nutrients are recovered, and profit is gained (*cf.* Tran-Thi *et al.* 2017). Successful farmers meet most challenges through agricultural intensification and adaptation to climate change. The local population becomes food and energy secure, provides food for the urban population and is a secure backbone for the national economy. By achieving key SDG targets, the nation gains international recognition, becoming a pioneer in sustainable agriculture and an example for other countries in creating a secure future.

Scenario 2: The middle way. At least traditional and adapted composting techniques, without using human excreta, are integrated into smallholder banana-coffee based farming systems in the Kagera region. The local population becomes almost food secure, except for a few weeks at the end of the dry season and the beginning of the rainy season, and part of the SDG target 2.4 is realised. However, deforestation only slowly decelerates because firewood continues to be used inefficiently as the only source of energy, migration to towns and city cannot be prevented and exports decline.

Scenario 3: Accepting the status quo. Hunger, starvation, illness, death, migration into cities, land-use conflicts, and severe environmental degradation remain high. National exports of banana and coffee decline dramatically.

[1] In German: *Bioabfallverordnung*. See https://www.bmu.de/gesetz/verordnung-ueber-die-verwertung-von-bioabfaellen-auf-landwirtschaftlich-forstwirtschaftlich-und-gaertn/ (accessed on 31st January 2021)

The nature of this approach is interdisciplinary and transdisciplinary. The melding of relevant knowledge by scientists from different disciplines, i.e., in this case environmental and social sciences and human medicine, as well as policy-/decision-makers, has been demanded by various authors for a long time, e.g., by Bouma and Montanarella (2016), Hoff (2018), and Pohl (2005).

6.4 Limitations

This research faced several limitations that are discussed in the following: First, the survey did not include soil sampling nor seasonal biomass and waste sampling. Also, seasonal water infiltration and evapotranspiration rates, and the weight of the livestock have not been measured. Hence, the harvest was estimated by the farmers, head of livestock count, and nutrient values taken from scientific literature. Second, the carbon cycle was beyond the scope of this thesis, although it is important in the context of climate change mitigation. Carbon storage is potentially high in the study area. Fourth, socio-economic conditions have not been studied in detail within the scope of this thesis. However, understanding how to overcome socio-economic constraints is crucial for further success and needs deeper analysis to overcome existing limitations in sustainable agricultural intensification. And fifth, a complex policy-related analysis would need to be made before developing policy advice. This thesis has sought to draw an outline of what this analysis might look like forming a starting point for future research.

6.5 Concluding discussion and recommendations

The integrated management of organic farm waste still plays a key role in farm nutrient and soil fertility management in smallholder banana-coffee-based farming systems in the Kagera region in NW Tanzania. This is particularly the case in farm households that have more than one hectare of homegarden, and, due to sufficient availability of labour, use a large part of the available organic waste as fertiliser. The advantages of an integrated organic farm management system are multiple: The decomposition of organic material supports humus accumulation and carbon storage, increases the stability of soil structure, and finally delivers nutrients, which are plant available under appropriate soil conditions.

However, in recent decades organic farm waste management has gradually lost its importance for several reasons. First, smallholder farming families have seen their socio-economic status weaken due to the outbreak of the HIV/AIDS pandemic, as well as population growth, hosting several hundred thousand refugees, and severe environmental degradation.

One result of this was that agricultural production has decreased and the transfer of knowledge on agricultural practices such as farm waste management has been interrupted from one generation to the next. As a second consequence, land sizes have decreased. More and more people are having to live on the same resources, such as land, water, and biomass, but their accessibility is constantly decreasing. Third, the impact of organic fertiliser on maintaining and improving soil properties cannot replace the nutrient withdrawal that takes place when crops and wood are harvested. The demand for soil nutrients to produce sufficient biomass in the form of food, firewood, and timber for the relatively high local population cannot be met at present. Soils will not recover from nutrient depletion until the full potential of organic farm waste is used as fertiliser and soil conditioner, and further measures are implemented. In addition, exports of bananas and coffee increase nutrient withdrawal from soils. If the region wants to become food secure and exports are to continue, action must be taken very soon. Otherwise, the degradation of land resources will worsen and jeopardise supplies for the population and exports.

Training in sustainable land-use management improves soil properties and food production, reduces poverty, and can also stabilise exports. Successfully implemented knowledge on soil and farm nutrient management including the introduction of trench composting, afforestation, selection of appropriate crop and tree species, as well as improved labour allocation and time management, agricultural record-keeping, and gender-responsive communication and decision-making can lead a transition from degraded to diverse, multifunctional agroforestry systems. Nutrient balances can be improved at farm level through the successful implementation of sustainable land management (SLM) practices. Degradation of soil and vegetation resources decreases after a few years on farms that have started the transition process. In farm households that successfully implement the training on SLM, farm nutrient balances (NBs) are positive across the board. In less successful households, NBs could be improved by utilising human urine, incorporating herbaceous legumes, and applying biochar and sanitised human excreta. Caution needs to be taken with regard to the system boundaries under consideration. 'Closed nutrient cycles' are only possible because nutrients are frequently imported to the homegardens. In the spirit of systems thinking, farmers are currently borrowing nutrients from the surrounding area. Nutrient deficiencies might be mitigated with the wise and precise application of mineral fertiliser. However, as long as these constraints remain, nutrient deficiencies will not be overcome solely by the use of organic or mineral fertilisers, either together or alone. Here, a system of agricultural extension services (eventually including soil tests) may be helpful.

Only about one third of the untrained farmers who have so far managed without agricultural training earn a reasonable living from their agricultural products and can at least send their children to primary school. Even they, however, go hungry for several months a year. The situation has considerably improved for 40% of the trained farm households, who have become food secure since implementing their training. In general, female-led households with a high age-dependency ratio remain the most vulnerable to food insecurity. This especially applies to farmers with problematic socio-economic backgrounds (e.g., single parents with several children, or those who are impoverished, sick, excluded from family or community, or who have access to limited labour), and to those who have started from scratch, such as newly settled Rwandan refugees. Such households are unable to improve their agricultural production and defy the degradation of soil and plant resources that affects the whole region.

However, the following limitations and dependencies remain even for farmers who are trained in sustainable land-use management: scarcity of land, labour-intensive collection and treatment techniques for organic farm waste, unsafe use of human excreta-derived fertilisers, food insecurity, socio-economic restrictions, limited access to mineral fertiliser, insufficient energy use, and exposure to climate change. Due to the scarcity of land resources per family, farmers hardly ever allow the soils to rest, either in the form of a fallow period or by cultivation with green manure in form of a cover crop that have the additional advantage of protecting soils against erosion and suppressing weed growth, e.g., with *Mucuna pruriens* L. and *Lablab purpureus* L. (*cf.* Eilittä *et al.* 2004).

To close knowledge gaps in farm waste management and minimise uncoordinated farm work, the communication culture within families should be improved by implementing a transparent information structure that strengthens cooperation among all family members. Involving all household members in farm work and decision-making processes decreases the risks of yield losses during times of illness. By extension, the community, e.g., a hamlet within a village or a ward, could develop a common responsibility on afforestation and farm waste management to create synergies beyond the individual farms, e.g., forest management, or turning coffee hulls and the invasive water hyacinth along the Kagera river into organic fertiliser (*cf*. Güereña *et al.* 2015). They could also develop strategies concerning how to produce CaSa-compost at local institutions, e.g., schools or hospitals, where people are already paid to empty pit latrines.

The main disadvantage of nearly all composting techniques is their labour-intensity. Besides, insufficient treatment of organic waste poses a potential health hazard to humans and animals. Ideally, the compost should be sanitised during the composting process before it is used as an organic fertiliser in crop production. Livestock manure is not sanitised before distribution in pit or ring-hole composting, and any pathogens that it contains may directly contaminate coffee and banana plants (*cf.* Jensen *et al.* 2008). With *in situ* composting, the possibility of contamination with pathogens is lower, as usually only plant-based waste is used. To solve this problem, it is crucial to start by analysing the entire pathobiome of the farming system to which the composted material is applied to avoid the spreading of human diseases (*cf.* Schneeberger *et al.* 2019). It is common practice among researchers to either assume that all pathogens and worm eggs are killed during the treatment phase of the composting process. This could be viewed as negligent, however, especially in regions where medical care is scarce and people often cannot afford medical treatment. When treated compost does undergo analysis, it is often revealed that some of these pathogens and eggs do indeed survive (*cf.* Schneeberger *et al.* 2019). In this context, the different composting techniques in varying climates and farming systems need to be taken into consideration in future analyses; this is particularly essential for the application of CaSa-compost on soils. In the future, the safe use of human excreta needs to be fostered in engineering and research. Advanced techniques need to be low-tech, affordable, able to be built by smallholder farmers themselves, and not labour-intensive. Soil samples need to be taken to analyse chemical, physical, and biological soil properties, and samples of organic farm waste must be obtained to estimate its nutrient content and to assess health risks for all household groups.

It is also important to mention that energy security has not been achieved by most of the farm households. Existing energy sources such as firewood and charcoal are not used in an efficient, ecological, or economically sustainable manner. In addition, farmers are still exposed to climate change, although the situation improves when climate change adaptation measures are implemented, such as the cultivation of drought-resistant crop species, the prevention of soil drying through mulching, increasing the water infiltration rate with trench composting along the contour lines, and improving food storage and preservation.

New research questions have emerged. It is still unclear why some farm households successfully implement the SLM training and others do not. It might be of particular interest to examine why farmers in Groups B_T and C_T fail in this, either partially or completely. We assume that the underlying reasons are social, psychological, and economic. For example, family size and support outside the core family, the effects of illness, alcoholism, coping with stressful long-term situations, and each household's financial starting point. One observation made in the field is that when hunger and disease prevail, farm management loses priority. This study is cross-sectorally linked to the Water-Energy-Food (WEF) Nexus and the Water-Soil-Waste Nexus (WSW). However, the 'water' component in both nexi should be further emphasised by enhancing water harvesting for domestic use and irrigation, providing drinking water treatment with advanced filtration techniques, and preventing wastewater leakage from pit latrines into underlying groundwater aquifers and adjacent surface water bodies. For any new application-oriented project, it would be highly recommended to involve local organisations. Only by integrating local knowledge could a profound analysis of socio-economic conditions succeed. In conclusion, further investigations need to be carried out, focusing on the socio-economic conditions and constraints, particularly of unsuccessful farming families. Any further separation of scientific disciplines would thus not be beneficial in this thematic scope. Indeed, there is a need for an increasing intermeshing of disciplines (interdisciplinarity) and increased cooperation between different experts and stakeholders such as farmers, politicians, scientists, engineers, and villagers (transdisciplinarity) – with the overarching guiding goals manifested in the SDGs.

Action needs to be taken and supporting policies and regulations need to be developed, e.g., on the safe use of organic farm waste, involving all stakeholders to contribute towards achieving some of the UN’s SDGs, especially SDG 2 (Zero hunger), SDG 7 (Affordable and clean energy), and SDG 15 (Life on land) for smallholder farming families, who are responsible for a major part of Africa's agricultural production. This thesis adds to the scientific community's knowledge of the sustainable restoration of degraded smallholder farming systems in East Africa and may serve as a basis for future development and further scientific research.

7 References

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8 Appendix

8.1 Data set of smallholder farm households

This chapter has been published as the following data article:

Reetsch, A., Schwärzel, K., Kapp, G., Dornack, C., Masisi, J., Alichard, L., Robert, H., Byamungu, G., Rocha, J. L., Stephene, S., Frederick, B., and Feger, K.-H. **2021a**. "Data Set of Smallholder Farm Households in Banana-Coffee-Based Farming Systems Containing Data on Farm Households, Agricultural Production and Use of Organic Farm Waste." *Data Brief*, 35, 106833, https://doi.org/10.1016/j.dib.2021.106833.

Data set of smallholder farm households in banana-coffee-based farming systems containing data on farm households, agricultural production and use of organic farm waste

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DOI of original article: 10.1016/j.agsy.2020.102915

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 Article history: received 22 December 2020, revised 22 January 2021, accepted 1 February 2021, available online 16 February 2021.

Abstract

The data was collected in the Karagwe and Kyerwa districts of the Kagera region in north-west Tanzania. It encompasses 150 smallholder farming households, which were interviewed on the composition of their household, agricultural production and use of organic farm waste. The data covers the two previous rainy seasons and the associated vegetation periods between September 2016 and August 2017. The knowledge of experts from the following institutions was included in the discussion on the selection criteria: two local non-profit organisations, i.e., WOMEDA and the MAVUNO Project; the International Institute of Tropical Agriculture (IITA); and the National Land Use Planning Commission (NLUPC). Households were selected for inclusion if all of the following applied to them: 1) less than 10 acres of land (4.7 ha) registered in the village offices, 2) no agricultural training, and 3) decline in the fertility of their land since they started farming (self-reported). We selected 150 smallholder households out of a pool of 5,000 households known to WOMEDA in six divisions of the Kyerwa and Karagwe districts. The questionnaire contained 54 questions. The original language of the survey was Kiswahili. All interviews were audio recorded. The answers were digitalised and translated into English. The data set contains the raw data with 130 quantitative and qualitative variables. For quantitative variables, the only analysis that was made was the conversion of units, e.g., land area was converted from acres to hectares, harvest from buckets to kilograms and then to tons, and heads of livestock to Tropical Livestock Units (TLU). Qualitative variables were summarised into categories. All data has been anonymised. The data set includes geographical variables, household information, agricultural information, gender-specific responsibilities, economic data, farm waste management, and water, energy and food availability (Water-Energy-Food (WEF) Nexus). Variables are written in italics. The following geographical variables are part of the data set: *district, division, ward, village, hamlet, longitude, latitude,* and *altitude*. Household information includes *start of farming, household size, gender* and *age of household members.* Agricultural information includes *land size, size of homegarden, crops, livestock* and *livestock-keeping, trees,* and *access to forest.* Gender-specific

responsibilities includes *producing* and *exchanging seeds, weed control, terracing, distributing organic material to the fields, care of annual* and *perennial crops, harvesting of crops, decisions about the harvest* and *animal products, selling* and *buying products, working on their own farm* and *off-farm, cooking, storing food, collecting and caring for drinking water, washing,* and *toilet cleaning.* Economic data includes *distance to the market, journey time to the market, transport methods, labourers* employed by the household*, working off-farm,* and assets such as *type of house*. Variables relevant to the WEF Nexus are *drinking water source* and *treatment, meals per day, months without food, cooking fuel,* and *type of toilet*. Variables on farm waste management are the *use of crop residues, food* and *kitchen waste, livestock manure, cooking ash, animal bones,* and *human urine* and *faeces.* The data can be potentially reused and further developed for the purpose of agricultural production analysis, socio-economic analysis, comparison to other regions, conceptualisation of waste and nutrient management, establishment of land use concepts, and further analysis on food security and healthy diets.

Keywords

Banana-coffee-based farming systems; food security; gender-based research; organic farm waste management; smallholder agriculture; soil fertility

8.1.1 Specifications table

Subject	Agricultural and Biological Sciences (General)
Specific subject area	The subject area is related to agricultural sciences involving agroforestry and connected to Circular Economy and waste management. 90% of banana-coffee farming systems are operated by smallholder farmers in East Africa. These farming systems are based on agroforestry with integrated composting of organic waste. However, due to severe degradation of vegetation and soils, as in north-west Tanzania, these farming systems have lost diversity and fertility.
Type of data	Table in Excel
How data were acquired	Survey, audio recorded and hand-noted questionnaire answers in Kiswahili, digitalised in Microsoft Excel, and translated into English.
Data format	Raw
Parameters for	We selected the data after discussion on the selection criteria and after consulting the relevant village officers. The following four institutions were involved in this discussion: two local non-profit organisations, i.e., WOMEDA (Women and Men for Destined

data collection	Achievements, facebook.com/Womeda-285166 84 8171570/) and the MAVUNO Project (mavunoproject.or.tz); the International Institute of Tropical Agriculture (IITA, iita.org/iita-countries/tanzania/); and the National Land Use Planning Commission (NLUPC, nlupc.go.tz). The criteria for smallholder farm households were the following: 1) less than 10 acres of land (4.7 ha) registered in the village offices, 2) no agricultural training, and 3) decline in the fertility of their land since they had started farming (self-reported). The data contains geographical variables, household data, agricultural data, economic data, data on water, energy and food, and farm waste management.
Description of data collection	First, we agreed on the selection criteria (see parameters for data collection). We selected the data after discussion on the selection criteria and after consulting the relevant village officers. The following four institutions were involved in this discussion: two local non-profit organisations, i.e., WOMEDA (Women and Men for Destined Achievements, facebook.com/Womeda-285166 84 8171570/) and the MAVUNO Project (mavunoproject.or.tz); the International Institute of Tropical Agriculture (IITA, iita.org/iita-countries/tanzania/); and the National Land Use Planning Commission (NLUPC, nlupc.go.tz). We visited the offices of each village and asked for permission to conduct the survey. Then we tested the questionnaire in the field and made the final changes. When selecting the study area within the Kagera region, it was important that the climatic and geomorphological conditions did not change within the study area. Furthermore, the area had to be as 'unexplored' as possible. Therefore, the Bukoba district, for example, was not suitable (lower altitude and different source rock than in Karagwe, with higher rainfall; many scientific studies). Secondly, language barriers had to be tackled and the farmers had to have confidence in the research team and agree to the survey itself and its recording. Therefore, the local non-governmental organisation WOMEDA, which has been working with about 5,0 0 0 local farming households since the 20 0 0s on issues such as malaria and AIDS prevention and disability, was involved in the data collection. It was also important that the survey area was not located in the divisions where the local Farmer Field School 'MAVUNO Project' has been active since the 1990s, in order to be able to subsequently compare the results of the survey with the success of the Farmer Field School's work. Therefore, the study area was reduced to 50 0 0 households in six divisions within the Karagwe and Kyerwa districts in the Kagera region. During the visits to the village officers, we also received accurate information on the current population figures within the divisions. In order to derive a representative statement, the sample size had to be at least 5% of the population under investigation. Therefore, we chose a sample size of 150 households, which, depending on the division, represented 5% to 10% of the population under investigation. Afterwards, we visited the selected families at home, either in their farmhouse or in the surrounding homegarden. We asked for permission to audio record the survey and to use the data for the purpose of research. We always used the same questionnaire. The surveying team conducted the survey in Kiswahili. If farmers answered in one of the local Kihaya languages, the answers were directly translated into Kiswahili and noted. The head of the household was interviewed in most cases; in 5% of the households the oldest son took his/her place. The answers given by the farmers were noted on the hard copy of the questionnaire and within a few days digitalised in MS Excel. All interviews were audio recorded. Finally, the answers were translated into English.

Data source location	Region: Kagera region District: Karagwe and Kyerwa Country: Tanzania, East Africa Latitude and longitude (and GPS coordinates) for surveyed farms: 30.7 and 31.5 E, and 1.2 and 1.8 S
Data accessibility	Repository name: PANGAEA Data identification number / Direct URL to data: https://doi.pangaea.de/10.1594/PANGAEA.914713 [1]
Related research article	Reetsch, Anika; Feger, Karl-Heinz; Schwärzel, Kai; Dornack, Christina; Kapp, Gerald (2020): Organic farm waste management in degraded banana-coffee-based farming systems in north-west Tanzania. In *Agric. Syst*. 185, p. 102915. https://doi.org/10.1016/j.agsy.2020.102915.

8.1.2 Value of the data

- The data is useful for agronomic analysis and to promote a deeper understanding of the agricultural production systems of smallholder farming families in the remote mountainous, sub-tropical Kagera region in north-west Tanzania, which has experienced long-term environmental degradation, refugee migration, and infection by HIV/AIDS.
- National and regional as well as non-governmental and governmental organisations and re- searchers can benefit from this data set. They can compare the region to other regions. Farmers indirectly benefit from the data, e.g., if governmental programmes use it to help frame land use policy or in farmer field schools to promote sustainable land use management.
- The data can be used to develop land use policies, to increase food security on a regional scale, to improve soil fertility farm waste management and thus nutrient management, to increase crop production, and to minimise environmental hazards in follow-up analyses.
- The data consists of gender-divided data, which is quite unique.
- The data set follows a holistic approach by combining the Water-Energy-Food Nexus, the Soil-Water-Waste Nexus, and other resource nexi.

8.1.3 Data description

The data file is an Excel table with three sheets, metadata, legend, and data. The data covers the two previous rainy seasons and the associated vegetation periods between September 2016 and August 2017.

The following geographical variables are part of the data set: *questionnaire identity number, date, time, district, division, ward, village, hamlet, longitude, latitude, altitude*. Household data encompasses *the earliest start of farming, latest start of farming, duration of farming, household size, male household members, female household members, household members below 14 years, household members between 14 and 50 years, household members above 50 years, age of head of household, gender of head of household.* Gender-divided responsibilities embrace the tasks of *"producing own seeds", "exchanging seeds", "weed control by tillage", "terracing", "distributing organic material to the field", "annual crops", "perennial crops", "harvest of crops", "decisions on harvest", "livestock- keeping", "decisions on animal products", "selling products", "buying food", "working on own farm", "working off-farm", "cooking", "storing food", "collecting and treating drinking water", "washing",* and *"toilet cleaning".*

Agricultural data refers to the *total land size, size of the homegarden* (in local language *kibanja*), *size of new farmland* (*kikamba*), *size of grassland* (*rweya*), *size of woodland* (*kabira*); the annual production of *coffee* (*Coffea canephora* L. var. *robusta*), *banana* (*Musa* L. spp.), *beans* (*Phaseolus vulgaris* and other spp.), *maize* (*Zea mays* L. spp.), and *cassava* (*Manihot esculenta* Crantz spp.); the livestock owned at the moment of surveying including *total Tropical Livestock Units* (TLU) divided into *Tropical Livestock Units kept on the farm* and *Total Tropical Livestock Units kept on grassland, heads of improved cattle (Friesian)* divided into *improved cattle kept on the farm* and *improved cattle kept on grassland, heads of indigenous cattle* divided into *indigenous cattle kept on the farm* and *indigenous cattle kept on grassland, heads of goats* divided into *goats kept on the farm* and *goats kept on grassland, heads of sheep* divided into *sheep kept on the farm* and *sheep kept on grassland, heads of pigs* divided into *pigs kept on the farm* and *pigs kept on grassland, heads of chicken* divided into *chicken kept on the farm* and *chicken kept on grassland*.

Economic data includes distance *to the market, journey time to the market, transport methods, labourers* employed by the household, *working off-farm*, and assets such as *type of house*. Further data on water, energy and food were collected: *water source, drinking water treatment, sanitation, energy source,* and *monthly food availability*. Farm waste management involved the *use of crop residues for composting, use of crop residues as fodder, use of food waste, use of kitchen waste, use of livestock manure, use of livestock urine, use of cooking ash, use of animal bones, use of human urine,* and *use of human faeces*.

8.1.4 Experimental design, materials, and methods

We formulated a questionnaire following [2]. The sample design was prepared according to [3] and [4]. Accordingly, we combined 54 open and closed questions in the survey, intending to transfer the answers given by the farmers directly into qualitative and quantitative variables. The questionnaire was prepared in English and translated into Kiswahili by the research team. If farmers answered in one of the local Kihaya languages, the answers were directly translated into Kiswahili and noted. We tested the questionnaire with 10 farmers in the field and trained the surveying team in conducting the survey similarly. After the testing phase, final changes were made to the questionnaire concerning repetition of questions to double-check the answers given, length of questions, methods of asking, and correctness of translation from English to Kiswahili.

In the field, we visited and observed the study area and talked to farmers, experts, and village officers. We selected the data after discussion on the selection criteria and after consulting the relevant village officers. The criteria for smallholder farm households were the following: 1) less than 10 acres of land (4.7 ha) registered in the village offices, 2) no agricultural training, and 3) decline in the fertility of their land since they had started farming (self-reported). The following four institutions were involved in this discussion: two local non-profit organisations, i.e., WOMEDA (Women and Men for Destined Achievements, facebook.com/Womeda-28516684 8171570/) and the MAVUNO Project (mavunoproject.or.tz); the International Institute of Tropical Agriculture (IITA, iita.org/iita-countries/tanzania/); and the National Land Use Planning Commission (NLUPC, nlupc.go.tz).

We visited the offices of each village and asked for permission to conduct the survey and to agree on which farm households fulfilled the criteria. Households were selected out of a pool of 5,000 farm households that were known to WOMEDA and affected by the degradation of vegetation and soils. The households were located in the Bugene, Nyaishozi, and Kituntu divisions of the Karagwe district and Kaisho, Mabira and Nkwenda divisions of the Kyerwa district. Of the 5,000 households meeting the criteria, we selected between 5% and 10% in each division. In total, we surveyed 12 villages in 6 divisions of the Kyerwa and Karagwe districts in the Kagera region of north-west Tanzania. During the survey phase, we visited the selected farming families at home, either in their farmhouse or in the surrounding homegarden. We asked for permission to audio record the sur- vey and to use the data for the purpose of research. We always used the same questionnaire. The surveying team conducted the survey in Swahili. The head of the household was interviewed in most cases; in 5% of the households the oldest son took his/her place. The answers given by the farmers were noted on the hard copy of the questionnaire and within a few days digitalised in MS Excel. All interviews were audio recorded. Finally, the answers were translated into English. Units of quantitative variables were harmonised, e.g., from acres to hectares, buckets to tons, and livestock to tropical livestock units according to [5]. Qualitative answers were shortened and, if needed, categorised following the method of qualitative content analysis after [6]. Different interpretations of the same response were avoided and checked. For example, the variable *food waste* derived from the question: "During the last year, what have you done with food waste?" Answers like "we do not have food waste" or "no food waste" or "we don't have any" were transformed into "not available" to make similar answers comparable with other answers and ready for statistical analysis. The survey answers are saved in the data set as raw data.

Ethics statement

All data is treated anonymously. In advance, all participating farmers agreed to the survey and the use of the data for non-profit research purposes. The farmers participated in the survey voluntarily. All participants have agreed in writing to the anonymised publication of the survey data.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal rela- tionships which have or could be perceived to have influenced the work reported in this article.

Acknowledgments

We cordially thank Sekela Twisa and Mohamed Mwabumba for hosting us in Dar es Salaam, and the MAVUNO Project for their sincere cooperation and for hosting us in Karagwe and in- troducing us to the Karagwe district. We thank the WOMEDA team for their close and sincere cooperation, without whom data collection would not have been possible; we appreciate the constant support, honest communication, and fun we had during the fieldwork. Lastly, we grate- fully acknowledge the United Nations University, the Heinrich Böll Foundation, and the Deutsche Gesellschaft für Abfallwirtschaft e. V. for funding, and Helen Grützner for her constant support and guidance in the editorial aspects of this article.

References

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8.2 Survey data

This data set has been published in Reetsch et al. (2020e), analysed in Reetsch et al. (2020c), and described in Reetsch et al. (2021).

Reetsch, A., Schwärzel, K., Kapp, G., Dornack, C., Masisi, J., Alichard, L., Robert, H., Byamungu, G., Stephene, S., and Feger, K.-H. **2020e**. "Survey of 150 Smallholder Farm Households in Banana-Coffee-Based Farming Systems Containing Data on Farm Households, Agricultural Production and Use of Farm Waste." *Pangaea*, https://doi.pangaea.de/10.1594/PANGAEA.914713.

8.2.1 Meta data

Table A 1: Meta data belonging to the survey data.

Title	Survey of 150 smallholder farm households in banana-coffee-based farming systems containing data on farm households, agricultural production and use of farm waste
Creator	Reetsch, Anika; Schwärzel, Kai; Kapp, Gerald; Dornack, Christina; Feger, Karl-Heinz
Subject	Agriculture; Environmental Sciences;
Description	This data set describes a survey in which 150 smallholder farming households participated in Karagwe and Kyerwa districts, Kagera region, Tanzania at the beginning of the rainy season between September and November 2017. The survey aimed to identify current uses of farm waste (including crop residues, food and kitchen waste, livestock manure and urine, cooking ash, animal bones, and human urine and faeces) and relate them to the agricultural production. Besides, this holistic survey encompasses gender-based household data. The data refers to two cropping seasons from September 2016 to August 2017 (12 months). The households have been selected after discussion with eight agricultural experts from Tanzania. All households were smallholder farming families in banana-coffee-based farming systems. All farms were affected by the degradation of vegetation and soil resources. They all reported that the productivity of their soils had been declined since they had started farming. None of the farmers applied mineral fertilizer to the soils, and none had received training in sustainable land use management yet, e.g., from a local farmer field school or governmental organization. The data set bases on a questionnaire that contained open and closed questions, a total of 54 questions, on household data, agricultural production and the use of organic farm waste. The original language of the survey was Kiswahili. If some

	farmers answered in local Haya languages, the answers were directly translated into Kiswahili and noted. After surveying, the answers were digitalized and translated into English. The dataset contains 130 quantitative/ qualitative variables. The original survey is attached to this data set.
Key words	organic farm waste management, soil fertility, food security, gender-based research, smallholder agriculture, banana-coffee-based farming systems
Location of study area	The study area is located between 1.0° to 2.1° S and 30.4° to 31.4° E in the Kagera region in NW Tanzania and covers seven wards of the Karagwe district (Kayanga, Nyakahanga, and Ndama wards in the Bugene division; Kituntu, Chanika, and Kihanga wards in the Kituntu division; and Nyaishozi ward in the Nyaishozi division), and six wards of the Kyerwa district (Isingiro ward in the Kaisho division; Kamuli, Kikukuru, and Kimuli wards in the Mabira division; and Nkwenda and Rukuraijo wards in the Nkwenda division. On the hilly terrain of the Karagwe Ankolean System, altitudes vary between 1,200 and 1,650 m above sea level.
Climatic condition of study area	The study region is characterised by a bimodal rain pattern with an annual rainfall between 716 and 1,286 mm (on average 982 mm ± 127 mm), and moderate temperatures with minimum mean temperatures between 11.6° C and 16.2° C and maximum between 24.6° C and 28.3 °C (Fig. 6; Touber and Kanani, 1996; TMA, 2017). The rain falls during the *Masika* rainy season from March to May and the *Vuli* rainy season from October to January.
Period of data collection	1st September to 30th November 2017
Period to which data refers	September 2016 to August 2017
Creation of data set	20th of August 2019
Technical assistance in data collection	The Tanzanian non-profit organisation WOMEDA. In-person, Juma Masisi, Leinalida Alichard, Harriet Robert and Godson Byamungu assisted in data collection and translation between local Haya languages, Kiswahili, and English.
Publisher	Technische Universität Dresden, Faculty of Environmental Sciences, Department of Forest Sciences, Institute of Soil Science and Site Ecology and Institute of International Forestry and Forest Products; United Nations University, Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES).
Type of data	Text, integer, decimal
Language	English

8.2.2 Geographical data

Table A 2: Legend of the geographical data.

Variable	Unit	Name	Description
QID	-	Questionnaire identity number	The identity number of each filled questionnaire.
DateTime	mm/dd/yyyy hh:mm:ss	Date and Time	The data and time the interview started.
District	-	District	The name of the district, in which the farm was located.
Division	-	Division	The name of the division, in which the farm was located.
Ward	-	Ward	The name of the ward, in which the farm was located.
Village	-	Village	The name of the village, in which the farm was located.
Hamlet	-	Hamlet	The name of the hamlet, in which the farm was located. A hamlet is a smaller unit within a village.
Longitude	-	Longitude	Longitude of the farm.
Latitude	-	Latitude	Latitude of the farm.
Altitude	-	Altitude	Altitude of the farm.

Table A 3: Geographical survey data.

QID	DateTime	District	Division	Ward	Village	Hamlet	Longitude	Latitude	Altitude
1	10/4/2017 11:15:00 AM	Kyerwa	Nkwenda	Nkwenda	Kakerere	Bigenyi "B"	30.8594580	-1.4753235	1306
2	10/4/2017 1:35:00 PM	Kyerwa	Nkwenda	Nkwenda	Kakerere	Bigenyi "B"	30.8589944	-1.4743850	1310
3	10/4/2017 4:30:00 PM	Kyerwa	Nkwenda	Nkwenda	Kakerere	Bigenyi "A"	30.8624805	-1.4750159	1308
4	10/6/2017 8:40:00 AM	Kyerwa	Nkwenda	Nkwenda	Kakerere	Bigenyi "B"	30.8617524	-1.4746886	1310
5	10/6/2017 11:50:00 AM	Kyerwa	Nkwenda	Nkwenda	Kakerere	Bigenyi "B"	30.8645221	-1.4808881	1275
6	10/6/2017 12:27:00 PM	Kyerwa	Nkwenda	Nkwenda	Kakerere	Bigenyi "B"	30.8565545	-1.4742649	1315
7	10/6/2017 2:10:00 PM	Kyerwa	Nkwenda	Nkwenda	Kakerere	Kakerere	30.8638770	-1.4909215	1286
8	10/6/2017 3:32:00 PM	Kyerwa	Nkwenda	Nkwenda	Kakerere	Makanzi	n.a.	-1.4804512	1377
9	10/9/2017 5:46:00 PM	Karagwe	Bugene	Kayanga	Rwamubale	Rwamubale	31.1165115	-1.5119552	1566
10	10/10/2017 10:36:00 AM	Karagwe	Bugene	Ndama	Nyabwegira	Nyarubale	31.1254085	-1.4915027	1635
11	10/10/2017 1:06:00 PM	Karagwe	Bugene	Ndama	Nyabwegira	Nyarubale	31.1228063	-1.4899657	1509
12	10/10/2017 1:30:00 PM	Karagwe	Bugene	Ndama	Nyabwegira	Nyabwegira "A"	31.1259677	-1.4972385	1514
13	10/10/2017 3:56:00 PM	Karagwe	Bugene	Ndama	Nyabwegira	Kilifunjo "A"	31.1313252	-1.4899504	1561

QID	DateTime	District	Division	Ward	Village	Hamlet	Longitude	Latitude	Altitude
14	10/10/2017 4:11:00 PM	Karagwe	Bugene	Ndama	Nyabwegira	Kilifunjo "B"	n.a.	n.a.	n.a.
15	10/11/2017 2:17:00 PM	Karagwe	Bugene	Nyakahanga	Bisheshe	Bisheshe	31.1130530	-1.6660689	1664
16	10/11/2017 11:25:00 AM	Karagwe	Bugene	Nyakahanga	Bisheshe	Rwandaro	31.1101873	-1.6702645	1678
17	10/11/2017 10:50:00 AM	Karagwe	Bugene	Nyakahanga	Bisheshe	Nyakasheshe	31.1187993	-1.6515887	1546
18	10/11/2017 1:04:00 PM	Karagwe	Bugene	Nyakahanga	Bisheshe	Nyakasheshe	31.1174059	-1.6557359	1584
19	10/11/2017 1:10:00 PM	Karagwe	Bugene	Nyakahanga	Bisheshe	Bisheshe	31.1134328	-1.6817720	n.a.
20	10/10/2017 4:25:00 PM	Karagwe	Bugene	Ndama	Nyabwegira	Kilifunjo "B"	31.1410664	-1.4882247	1596
21	11/10/2017 2:46:00 AM	Karagwe	Nyaishozi	Nyaishozi	Nyakayanja	Kishanshamuzi	31.1296264	-1.6594266	1579
22	10/11/2017 3:38:00 PM	Karagwe	Bugene	Nyakahanga	Bisheshe	Nyamabale	31.1316793	-1.6777307	n.a.
23	10/11/2017 5:50:00 PM	Karagwe	Bugene	Nyakahanga	Bisheshe	Rwanda	31.1449626	-1.6650161	1639
24	10/11/2017 5:31:00 PM	Karagwe	Bugene	Nyakahanga	Bisheshe	Rwanda	31.1446799	-1.6647317	1630
25	10/16/2017 11:24:00 AM	Karagwe	Nyaishozi	Nyaishozi	Nyakayanja	Kishanshamuzi	31.1150622	-1.7310130	1421
26	10/16/2017 11:33:00 AM	Karagwe	Nyaishozi	Nyaishozi	Nyakayanja	Nyamihingo	31.1134510	-1.7400412	1461
27	10/16/2017 11:37:00 AM	Karagwe	Nyaishozi	Nyaishozi	Nyakayanja	Chakahaya	31.1125119	-1.7341806	1435
28	10/16/2017 1:30:00 PM	Karagwe	Nyaishozi	Nyaishozi	Nyakayanja	Mugaba	31.1142955	-1.7236525	n.a.
29	10/16/2017 1:35:00 PM	Karagwe	Nyaishozi	Nyaishozi	Nyakayanja	Mugaba	31.1139700	-1.7225958	1424
30	10/16/2017 1:50:00 PM	Karagwe	Nyaishozi	Nyaishozi	Nyakayanja	Mugaba	31.1160703	-1.7209302	n.a.
31	10/16/2017 4:14:00 PM	Karagwe	Nyaishozi	Nyaishozi	Nyakayanja	Nyakayanja	31.1069105	-1.7113705	n.a.
32	10/16/2017 4:20:00 PM	Karagwe	Nyaishozi	Nyaishozi	Nyakayanja	Nyakayanja	31.1057126	-1.7091131	1540
33	10/16/2017 3:10:00 PM	Karagwe	Nyaishozi	Nyaishozi	Nyakayanja	Mubutoma	31.1034486	-1.7035968	n.a.
34	10/17/2017 9:34:00 AM	Karagwe	Kituntu	Kihanga	Kishoju	Nyamanoro	31.1722676	-1.4717524	1228
35	10/17/2017 9:00:00 AM	Karagwe	Kituntu	Kihanga	Kishoju	Nyamanoro	31.1730644	-1.4705010	1228
36	10/17/2017 10:07:00 AM	Karagwe	Kituntu	Kihanga	Kishoju	Ahakashashabo	31.1747870	-1.4666667	1212
37	10/17/2017 11:20:00 AM	Karagwe	Kituntu	Kihanga	Kishoju	Sinza	31.1705507	-1.4744968	1230
38	10/17/2017 11:10:00 AM	Karagwe	Kituntu	Kihanga	Kishoju	Sinza	31.1694996	-1.4736004	1246
39	10/17/2017 11:40:00 AM	Karagwe	Kituntu	Kihanga	Kishoju	Chinyamataho	31.1031803	-1.2002942	n.a.
40	10/17/2017 1:00:00 PM	Karagwe	Kituntu	Kihanga	Kishoju	Nyarutunga	31.4369889	-1.7042410	n.a.
41	10/17/2017 1:08:00 PM	Karagwe	Kituntu	Kihanga	Kishoju	Nyalutunga	31.1752809	-1.4642916	1235
42	10/17/2017 9:00:00 AM	Karagwe	Kituntu	Kihanga	Kishoju	Kashashabo	31.1734248	-1.4737243	n.a.
43	10/17/2017 3:00:00 PM	Karagwe	Kituntu	Kihanga	Kishoju	Miembeni	31.1780967	-1.4723311	n.a.
44	10/17/2017 3:07:00 PM	Karagwe	Kituntu	Kihanga	Kishoju	Miembeni	31.1761129	-1.4740354	1212
45	10/17/2017 5:05:00 PM	Karagwe	Kituntu	Kihanga	Kishoju	Kishoju "A"	31.1768227	-1.4767361	n.a.

QID	DateTime	District	Division	Ward	Village	Hamlet	Longitude	Latitude	Altitude
46	10/18/2017 8:47:00 AM	Karagwe	Kituntu	Kituntu	Kituntu	Kinyinya	31.1768523	-1.4758873	n.a.
47	10/18/2017 9:00:00 AM	Karagwe	Kituntu	Kituntu	Kituntu	Kinyinya	31.0876638	-1.3918400	n.a.
48	10/18/2017 5:10:00 PM	Karagwe	Kituntu	Kituntu	Kituntu	Kinyinya	31.0976607	-1.3851015	1521
49	10/18/2017 9:04:00 AM	Karagwe	Kituntu	Kituntu	Kituntu	Kinyinya	31.0873003	-1.3947137	1518
50	10/18/2017 11:12:00 AM	Karagwe	Kituntu	Kituntu	Kituntu	Nyakashozi	31.1143723	-1.3511748	n.a.
51	10/18/2017 1:08:00 PM	Karagwe	Kituntu	Kituntu	Kituntu	Nyakashozi	31.1085214	-1.3750785	1592
52	10/18/2017 11:48:00 AM	Karagwe	Kituntu	Kituntu	Kituntu	Kinyinya	31.0938815	-1.3864764	1514
53	10/18/2017 2:40:00 PM	Karagwe	Kituntu	Kituntu	Kituntu	Nyakashozi	31.1100486	-1.3726716	n.a.
54	10/18/2017 5:20:00 PM	Karagwe	Kituntu	Kituntu	Kituntu	Nyaruhanga	31.1132960	-1.3727281	n.a.
55	10/18/2017 1:08:00 PM	Karagwe	Kituntu	Kituntu	Kituntu	Nyakashozi	31.1103588	-1.3700158	1598
56	10/18/2017 1:22:00 PM	Karagwe	Kituntu	Kituntu	Kituntu	Nyakashozi	31.1088259	-1.3759144	n.a.
57	10/18/2017 5:20:00 PM	Karagwe	Kituntu	Kituntu	Kituntu	Nyaruhanga	31.1155220	-1.3797763	n.a.
58	10/18/2017 2:49:00 PM	Karagwe	Kituntu	Kituntu	Kituntu	Nyakashozi	31.1110014	-1.3711498	1597
59	10/18/2017 4:32:00 PM	Karagwe	Kituntu	Kituntu	Kituntu	Nyaruhanga	31.1166896	-1.3775090	n.a.
60	10/18/2017 4:28:00 PM	Karagwe	Kituntu	Kituntu	Kituntu	Nyaruhanga	31.1157737	-1.4345173	1609
61	10/19/2017 10:00:00 AM	Karagwe	Kituntu	Chanika	Chanika	Busecha	31.0838894	-1.4513880	n.a.
62	10/19/2017 10:09:00 AM	Karagwe	Kituntu	Chanika	Chanika	Busecha	31.0816290	-1.4479339	1561
63	10/19/2017 9:49:00 AM	Karagwe	Kituntu	Chanika	Chanika	Busecha	31.0909635	-1.4486771	n.a.
64	10/19/2017 11:56:00 AM	Karagwe	Kituntu	Chanika	Chanika	Busecha	31.0838923	-1.4680861	n.a.
65	10/19/2017 12:03:00 PM	Karagwe	Kituntu	Chanika	Chanika	Rushalazi	31.0906628	-1.4422551	1545
66	10/19/2017 9:49:00 AM	Karagwe	Kituntu	Chanika	Chanika	Busecha	31.0814617	-1.4464701	n.a.
67	10/19/2017 2:26:00 PM	Karagwe	Kituntu	Chanika	Chanika	Chaibumba	31.0976757	-1.4322722	n.a.
68	10/19/2017 2:25:00 PM	Karagwe	Kituntu	Chanika	Chanika	Chaibumba	31.0982828	-1.4340054	1562
69	10/19/2017 2:42:00 PM	Karagwe	Kituntu	Chanika	Chanika	Chaibumba	31.0999974	-1.4345014	1566
70	10/19/2017 4:11:00 PM	Karagwe	Kituntu	Chanika	Chanika	Buliguru	31.0902376	-1.4179269	n.a.
71	10/19/2017 4:09:00 PM	Karagwe	Kituntu	Chanika	Chanika	Chaibumba	31.0969033	-1.4292236	1559
72	10/19/2017 4:20:00 PM	Karagwe	Kituntu	Chanika	Chanika	Buliguru	31.0925166	-1.4344913	n.a.
73	10/19/2017 6:00:00 AM	Karagwe	Kituntu	Chanika	Chanika	Binengo "A"	31.0999337	-1.4400962	1584
74	10/19/2017 4:10:00 PM	Karagwe	Kituntu	Chanika	Chanika	Mugando	31.1020793	-1.4440831	1558
75	10/19/2017 6:40:00 PM	Karagwe	Kituntu	Chanika	Chanika	Ngando	31.1003672	-1.4441731	1553
76	11/2/2017 10:19:00 AM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Omukachato	31.0954081	-1.4481418	1425
77	11/2/2017 10:40:00 AM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Omukachato	30.8630156	-1.4507756	1446

QID	DateTime	District	Division	Ward	Village	Hamlet	Longitude	Latitude	Altitude
78	11/2/2017 12:20:00 PM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Omukachato	30.8635600	-1.4757700	n.a.
79	11/2/2017 11:55:00 AM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Kitembe	30.8674800	-1.4504122	1401
80	11/2/2017 1:15:00 PM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Omukachato	30.8740300	-1.4451000	n.a.
81	11/2/2017 12:28:00 PM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Kitembe	30.8690964	-1.4333333	1382
82	11/2/2017 2:00:00 PM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Kitembe	30.8640900	-1.4769700	n.a.
83	11/2/2017 2:00:00 PM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Rukuraijo "A"	30.8640100	-1.4451000	n.a.
84	11/2/2017 1:41:00 PM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Rukuraijo "A"	30.8696322	-1.4515601	1376
85	11/2/2017 4:05:00 PM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Kitembe	30.8717000	-1.4501148	1347
86	11/2/2017 3:29:00 PM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Rukuraijo "A"	30.8640800	-1.4770300	n.a.
87	11/2/2017 5:37:00 PM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Kitembe	30.8714262	-1.4505044	1350
88	11/2/2017 5:02:00 PM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Rukuraijo "A"	30.8641700	-1.4768900	n.a.
89	11/2/2017 2:51:00 PM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Kitembe	30.8737159	-1.4477268	1290
90	10/18/2017 4:28:00 PM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Rukuraijo	30.8699156	-1.4581082	1331
91	11/2/2017 6:02:00 PM	Kyerwa	Nkwenda	Rukuraijo	Rukuraijo	Kitembe	30.8726808	-1.4514294	1357
92	11/3/2017 8:45:00 AM	Kyerwa	Kaisho	Isingiro	Kihanga	Kamachwele	30.8726754	-1.4514285	n.a.
93	11/3/2017 9:02:00 AM	Kyerwa	Kaisho	Isingiro	Kihanga	Kamachwele	30.8641300	-1.4769000	n.a.
94	11/3/2017 10:11:00 AM	Kyerwa	Kaisho	Isingiro	Kihanga	Rwenyana	30.8641700	-1.4769000	n.a.
95	11/3/2017 10:00:00 AM	Kyerwa	Kaisho	Isingiro	Kihanga	Rukuraijo	30.7045766	-1.2804335	1349
96	11/3/2017 10:28:00 AM	Kyerwa	Kaisho	Isingiro	Kihanga	Rukuraijo	30.7077089	-1.2837710	1350
97	11/3/2017 12:00:00 PM	Kyerwa	Kaisho	Isingiro	Kihanga	Kihanga	30.7198946	-1.2890330	1386
98	11/3/2017 1:32:00 PM	Kyerwa	Kaisho	Isingiro	Kihanga	Kabuyanda	30.8640900	-1.4769800	n.a.
99	11/3/2017 12:24:00 PM	Kyerwa	Kaisho	Isingiro	Kihanga	Kabuyanda	30.7206468	-1.2960736	n.a.
100	11/3/2017 2:20:00 PM	Kyerwa	Kaisho	Isingiro	Kihanga	Nshozi	30.7166170	-1.2961025	1352
101	11/3/2017 2:54:00 PM	Kyerwa	Kaisho	Isingiro	Kihanga	Nyamiyaga	30.8640200	-1.4768800	n.a.
102	11/3/2017 3:50:00 PM	Kyerwa	Kaisho	Isingiro	Kihanga	Kibale	30.7160390	-1.3046995	1360
103	11/3/2017 2:23:00 PM	Kyerwa	Kaisho	Isingiro	Kihanga	Kibale	30.7176038	-1.3033133	1341
104	11/3/2017 4:25:00 PM	Kyerwa	Kaisho	Isingiro	Kihanga	Nyamiyaga	30.8640100	-1.4769400	n.a.
105	11/3/2017 4:11:00 PM	Kyerwa	Murongo	Kaisho	Kihanga	Kibale	30.7119612	-1.3028318	1338
106	11/4/2017 9:45:00 AM	Kyerwa	Mabira	Kamuli	Kamuli	Ahakishenyi	30.7119732	-1.3028476	n.a.
107	11/4/2017 9:58:00 AM	Kyerwa	Mabira	Kamuli	Kamuli	Omukashenyi	30.8640200	-1.4768100	n.a.
108	11/4/2017 9:51:00 AM	Kyerwa	Mabira	Kamuli	Kamuli	Mukasenyi	30.8777602	-1.2975845	1782
109	11/4/2017 11:20:00 AM	Kyerwa	Mabira	Kamuli	Kamuli	Nyakatabe	30.8639700	-1.4767600	n.a.

QID	DateTime	District	Division	Ward	Village	Hamlet	Longitude	Latitude	Altitude
110	11/4/2017 11:20:00 AM	Kyerwa	Mabira	Kamuli	Kamuli	Nyakatabe	30.8640100	-1.4766600	n.a.
111	11/4/2017 1:07:00 PM	Kyerwa	Mabira	Kamuli	Kamuli	Nyakatabe	30.8515390	-1.2986531	1631
112	11/4/2017 12:49:00 PM	Kyerwa	Mabira	Kamuli	Kamuli	Nyakatabe	30.8639500	-1.4767200	n.a.
113	11/4/2017 11:48:00 AM	Kyerwa	Mabira	Kamuli	Kamuli	Nyakatabe	30.8505957	-1.2976005	1635
114	11/4/2017 3:01:00 PM	Kyerwa	Mabira	Kamuli	Kamuli	Kamuli "A"	30.8639900	-1.4766300	n.a.
115	11/4/2017 2:04:00 PM	Kyerwa	Mabira	Kamuli	Kamuli	Kamuli "B"	30.8639300	-1.4767200	n.a.
116	11/4/2017 1:16:00 PM	Kyerwa	Mabira	Kamuli	Kamuli	Kamuli "B"	30.8729300	-1.3014562	1636
117	11/4/2017 4:37:00 PM	Kyerwa	Mabira	Kamuli	Kamuli	Ruteme	30.8559476	-1.2808820	1685
118	11/4/2017 3:38:00 PM	Kyerwa	Mabira	Kamuli	Kamuli	Ruteme	30.8639900	-1.4765900	n.a.
119	11/4/2017 3:29:00 PM	Kyerwa	Mabira	Kamuli	Kamuli	Kamuli "A"	30.8557411	-1.2918417	1743
120	11/3/2017 11:10:00 AM	Kyerwa	Kaisho	Isingiro	Kihanga	Kigarama	30.8641200	-1.4769200	n.a.
121	11/3/2017 8:51:00 AM	Kyerwa	Kaisho	Isingiro	Kihanga	Kamachwere	30.7065511	-1.2789637	1379
122	11/7/2017 10:33:00 AM	Kyerwa	Mabira	Kikukuru	Mukunyu	Busingo "A"	30.9153315	-1.3358265	1563
123	11/7/2017 10:35:00 AM	Kyerwa	Mabira	Kikukuru	Mukunyu	Busingo "B"	30.9152260	-1.3316853	1580
124	11/1/2017 10:39:00 AM	Kyerwa	Mabira	Kikukuru	Mukunyu	Busingo "B"	30.8640300	-1.4766600	n.a.
125	11/7/2017 12:05:00 PM	Kyerwa	Mabira	Kikukuru	Mukunyu	Busingo "A"	30.9144364	-1.3283175	1567
126	11/7/2017 12:00:00 PM	Kyerwa	Mabira	Kikukuru	Mukunyu	Busingo "A"	30.8639500	-1.4766200	n.a.
127	11/7/2017 11:45:00 AM	Kyerwa	Mabira	Kikukuru	Mukunyu	Mukunyu "B"	30.9129723	-1.3322010	1593
128	11/7/2017 1:32:00 PM	Kyerwa	Mabira	Kikukuru	Mukunyu	Busingo "B"	30.8640100	-1.4766800	n.a.
129	10/18/2017 4:28:00 PM	Kyerwa	Mabira	Kikukuru	Mukunyu	Busingo "A"	31.1157737	-1.4345173	1609
130	11/7/2017 1:02:00 PM	Kyerwa	Mabira	Kikukuru	Mukunyu	Busingo "A"	30.8640500	-1.4766900	n.a.
131	11/7/2017 2:50:00 PM	Kyerwa	Mabira	Kikukuru	Mukunyu	Mukunyu "B"	30.8639900	-1.4767100	n.a.
132	11/7/2017 2:21:00 PM	Kyerwa	Mabira	Kikukuru	Mukunyu	Busingo "A"	30.9098182	-1.3333819	1554
133	11/7/2017 2:55:00 PM	Kyerwa	Mabira	Kikukuru	Mukunyu	Mukunyu "B"	30.8639800	-1.4767200	n.a.
134	11/7/2017 4:25:00 PM	Kyerwa	Mabira	Kikukuru	Mukunyu	Mukunyu "B"	30.9071583	-1.3346146	1614
135	11/7/2017 4:14:00 PM	Kyerwa	Mabira	Kikukuru	Mukunyu	Mukunyu "B"	30.8639900	-1.4767200	n.a.
136	11/7/2017 3:22:00 PM	Kyerwa	Mabira	Kikukuru	Mukunyu	Mukunyu "B"	30.9082073	-1.3259167	1605
137	11/8/2017 10:00:00 AM	Kyerwa	Mabira	Kimuli	Kimuli	Chakalalama "A"	30.8639800	-1.4767400	n.a.
138	11/8/2017 9:28:00 AM	Kyerwa	Mabira	Kimuli	Kimuli	Chakalalama "B"	30.9333374	-1.4173254	1281
139	11/8/2017 10:30:00 AM	Kyerwa	Mabira	Kimuli	Kimuli	Chakalalama "A"	30.8739800	-1.4451100	n.a.
140	11/8/2017 11:40:00 AM	Kyerwa	Mabrira	Kimuli	Kimuli	Omurutongole	30.8639900	-1.4768300	n.a.
141	11/8/2017 11:33:00 AM	Kyerwa	Mabira	Kimuli	Kimuli	Kataba	30.8639800	-1.4767300	n.a.

QID	DateTime	District	Division	Ward	Village	Hamlet	Longitude	Latitude	Altitude
142	11/8/2017 11:31:00 AM	Kyerwa	Mabira	Kimuli	Kimuli	Kataba	30.9450573	-1.3960230	1279
143	11/8/2017 1:50:00 PM	Kyerwa	Mabira	Kimuli	Kimuli	Chabisheke	30.8639700	-1.4768500	n.a.
144	11/8/2017 12:30:00 PM	Kyerwa	Mabira	Kimuli	Kimuli	Chabisheke	30.8639900	-1.4768200	n.a.
145	11/8/2017 1:34:00 PM	Kyerwa	Mabira	Kimuli	Kimuli	Kataba	30.9419253	-1.3965125	1336
146	11/8/2017 2:00:00 PM	Kyerwa	Mabira	Kimuli	Kimuli	Chakalalama	30.8736800	-1.4451100	n.a.
147	11/8/2017 3:30:00 PM	Kyerwa	Mabira	Kimuli	Kimuli	Chakalalama "A"	30.9415170	-1.4090239	1317
148	11/8/2017 1:55:00 PM	Kyerwa	Mabira	Kimuli	Kimuli	Chabisheke	30.8640000	-1.4768800	n.a.
149	11/8/2017 5:00:00 PM	Kyerwa	Mabira	Kimuli	Kimuli	Bitetea	30.8739800	-1.4451200	n.a.
150	11/8/2017 3:54:00 PM	Kyerwa	Mabira	Kimuli	Kimuli	Kabwera "B"	30.8739800	-1.4451100	n.a.

8.2.4 Household information

Table A 4: Legend of the household information.

Variable	Unit	Name	Description
HouseholdSize	pers.	Household size	Household size.
Male	pers.	Male household members	Number of male household members.
Female	pers.	Female household members	Number of female household members.
Below14	pers.	Household members below 14 years	Number of household members below 14 years.
14-50	pers.	Household members between 14 and 50 years	Number of household members between 14 and 50 years.
Above50	pers.	Household members above 50 years	Number of household members above 50 years.
HeadAge	yr	Age of the head of household	Age of the head of household.
HeadGender	male/female	Gender of the head of household	Gender of the head of household.

Table A 5: Household information.

QID	HouseholdSize	Male	Female	Below14	14-50	Above50	HeadAge	HeadGender
1	6	5	1	0	6	0	49	male
2	8	4	4	4	4	0	42	male
3	6	1	5	5	0	1	52	female
4	12	3	9	2	7	3	60	male
5	7	4	3	3	1	3	81	male
6	14	3	11	9	5	0	42	male
7	6	4	2	3	3	0	40	female
8	21	11	9	2	16	3	59	male
9	15	n.a.	n.a.	2	11	2	53	male
10	10	3	7	2	8	0	43	male
11	7	2	5	2	3	2	62	male
12	5	3	2	3	2	0	33	male
13	7	5	2	4	3	0	49	male
14	5	2	3	1	3	1	61	female
15	10	5	5	3	6	1	53	male

QID	HouseholdSize	Male	Female	Below14	14-50	Above50	HeadAge	HeadGender
16	9	4	5	4	3	2	76	male
17	6	2	4	4	2	0	30	male
18	8	4	4	6	2	0	51	male
19	6	5	1	4	2	0	26	female
20	5	4	1	1	3	1	57	male
21	15	10	5	5	9	1	67	male
22	25	n.a.	n.a.	8	9	8	63	female
23	6	3	3	4	2	0	55	male
24	4	2	2	1	3	1	63	male
25	46	n.a.	n.a.	11	23	11	56	male
26	7	2	5	3	4	0	48	male
27	2	1	1	0	0	2	59	male
28	7	0	7	2	4	1	54	male
29	20	n.a.	n.a.	0	18	2	55	male
30	5	1	4	2	2	1	49	female
31	5	1	4	3	2	0	26	female
32	17	n.a.	n.a.	0	16	1	60	male
33	2	1	1	0	0	2	26	female
34	3	2	1	0	1	2	57	male
35	6	2	4	4	2	0	40	male
36	9	2	7	7	0	2	67	female
37	7	6	1	4	3	0	36	male
38	6	3	3	1	5	0	38	female
39	9	4	5	4	5	0	35	female
40	9	4	5	0	5	4	59	male
41	4	1	3	1	3	0	26	male
42	8	5	3	3	4	1	74	male
43	5	2	3	3	2	0	33	female
44	5	2	3	3	2	0	36	male
45	7	3	4	2	3	3	63	male
46	5	3	2	0	3	2	58	female
47	5	0	5	0	4	1	52	female

QID	HouseholdSize	Male	Female	Below14	14-50	Above50	HeadAge	HeadGender
48	7	4	3	3	3	1	60	female
49	5	4	1	3	2	0	35	female
50	11	5	6	4	6	1	69	female
51	6	2	4	4	1	2	58	female
52	5	2	3	3	2	0	40	male
53	8	4	4	2	4	2	63	male
54	8	5	3	3	4	1	55	male
55	4	2	2	0	3	1	51	male
56	12	8	4	1	9	2	56	male
57	6	4	2	1	3	2	56	male
58	6	4	2	3	3	0	54	male
59	5	2	3	3	2	0	36	male
60	16	13	3	9	6	1	54	female
61	7	5	2	1	5	1	47	male
62	7	1	6	4	2	1	54	female
63	5	3	2	0	4	1	55	male
64	7	3	4	3	3	1	61	female
65	10	2	8	3	7	0	47	female
66	9	3	6	5	4	0	36	male
67	12	5	7	6	6	0	47	male
68	12	6	6	4	6	2	79	male
69	6	4	2	4	2	0	35	male
70	6	2	4	4	2	0	38	male
71	9	3	6	0	7	2	71	male
72	10	4	6	4	5	1	53	male
73	29	n.a.	n.a.	0	22	7	79	male
74	7	3	4	1	5	1	62	female
75	4	2	2	1	3	1	55	female
76	3	2	1	0	2	1	64	female
77	4	0	4	2	1	1	74	female
78	7	3	4	0	6	1	56	female
79	10	6	4	3	6	1	54	male

QID	HouseholdSize	Male	Female	Below14	14-50	Above50	HeadAge	HeadGender
80	21	13	8	7	13	1	57	male
81	7	3	4	1	4	2	58	male
82	23	13	10	5	14	4	74	male
83	5	1	4	2	1	2	60	male
84	7	2	5	3	3	1	n.a.	female
85	8	3	5	3	5	0	43	male
86	10	6	4	2	7	1	52	male
87	4	2	2	1	3	0	48	female
88	3	1	2	1	1	1	92	female
89	5	4	1	3	0	2	64	male
90	4	3	1	2	2	0	45	female
91	6	3	3	3	2	1	72	female
92	1	1	0	0	1	0	26	male
93	12	6	6	1	10	1	53	male
94	8	3	5	2	6	0	49	male
95	9	3	6	2	6	1	51	female
96	4	2	2	3	1	0	59	female
97	11	8	3	3	8	0	49	male
98	8	3	5	3	5	0	42	female
99	6	4	2	3	3	0	46	male
100	7	3	5	3	4	0	44	female
101	4	2	2	1	2	1	62	female
102	8	6	2	3	4	1	53	male
103	8	4	4	6	2	0	44	male
104	11	2	9	7	2	2	52	female
105	4	2	2	2	1	1	78	female
106	12	3	9	11	0	1	56	female
107	6	3	3	3	3	0	47	male
108	10	5	5	3	6	1	59	male
109	6	2	4	1	3	2	57	male
110	8	5	3	2	5	1	54	male
111	3	1	2	n.a.	n.a.	n.a.	23	male

QID	HouseholdSize	Male	Female	Below14	14-50	Above50	HeadAge	HeadGender
112	6	4	2	3	3	0	39	male
113	23	n.a.	n.a.	11	12	0	42	male
114	9	4	5	3	6	0	45	male
115	9	7	2	3	6	0	47	male
116	7	5	2	0	5	2	55	male
117	16	10	6	4	9	3	72	male
118	7	3	4	3	4	0	43	male
119	5	2	3	1	4	0	44	female
120	8	4	4	1	6	1	61	female
121	5	2	1	4	1	0	36	female
122	14	7	7	6	8	0	45	male
123	8	4	4	3	4	1	53	female
124	10	8	3	2	6	3	56	male
125	7	5	2	1	6	0	45	male
126	6	4	2	3	0	3	61	female
127	5	2	3	3	2	0	30	male
128	6	4	2	3	3	0	29	male
129	10	4	6	3	5	2	54	female
130	14	7	7	2	11	1	51	female
131	50	n.a.	n.a.	14	31	5	56	male
132	2	1	1	0	0	2	60	male
133	5	2	3	3	1	1	66	male
134	5	3	2	2	3	0	40	female
135	6	2	4	4	1	1	60	male
136	8	4	4	5	3	0	38	male
137	13	7	6	6	7	0	42	male
138	16	8	8	10	5	1	51	male
139	8	4	4	4	3	1	53	male
140	18	10	8	10	7	7	59	male
141	8	4	4	3	5	0	45	male
142	8	3	5	5	3	0	45	male
143	7	4	3	3	4	0	45	male

QID	HouseholdSize	Male	Female	Below14	14-50	Above50	HeadAge	HeadGender
144	7	1	6	3	4	0	50	female
145	9	4	5	1	7	1	47	male
146	7	3	4	5	1	1	39	female
147	2	1	1	1	1	0	55	female
148	7	3	4	4	1	2	82	male
149	7	2	5	4	3	0	44	male
150	8	3	5	3	5	0	46	male

8.2.6 Agricultural information

Table A 6: Legend of the agricultural information.

Variable	Unit	Name	Description
TotLand	ha	Total land size	The total land size involving all land parcels of homegarden, new farmland, grassland, and woodland. Usually, one banana-coffee-based farming system consists of all four types of land-use.
Homegarden	ha	Size of the homegarden	Size of the homegarden.
NewFarm	ha	Size of new farmland	Size of new farmland.
Grassland	ha	Size of grassland	Size of grassland.
Woodland	ha	Size of woodland	Size of woodland.
Coffee	t yr^{-1} $homegarden^{-1}$	Annual coffee *(Coffea canephora L. var. robusta)* harvest	Annual coffee *(Coffea canephora L. var. robusta)* harvest produced in the homegarden between September 2016 and August 2017.
Banana	t yr^{-1} $homegarden^{-1}$	Annual banana *(Musa L. spp.)* harvest	Annual banana *(Musa L. spp.)* harvest produced in the homegarden between September 2016 and August 2017.
Beans	t yr^{-1} $homegarden^{-1}$	Annual beans *(Phaseolus vulgaris, spp.)* harvest	Annual beans *(Phaseolus vulgaris, spp.)* harvest produced in the homegarden between September 2016 and August 2017.
Maize	t yr^{-1} $homegarden^{-1}$	Annual maize *(Zea mays L., spp.)* harvest	Annual maize *(Zea mays L., spp.)* harvest produced in the homegarden between September 2016 and August 2017.
Cassava	t yr^{-1} $homegarden^{-1}$	Annual cassava *(Manihot esculenta Crantz, spp.)* harvest	Annual cassava *(Manihot esculenta Crantz, spp.)* harvest produced in the homegarden between September 2016 and August 2017.
TotTLU	TLU	Total tropical livestock units	1 TLU = 250 kg; all livestock belonging to one farm household
TLUHome	TLU	Tropical livestock units kept in the farm	1 TLU = 250 kg. Livestock kept on the farm (homegarden and new farmland) belonging to one farm household.
TLUGrass	TLU	Tropical livestock units kept in the grassland	1 TLU = 250 kg. Livestock kept on the grassland belonging to one farm household.
ImCattle	head	Heads of improved cattle (Friesian)	Number of improved cattle (Friesian) per household.
ImCattleFarm	yes/no	Improved cattle kept in the farm	Number of improved cattle (Friesian) kept in the farm (homegarden and new farmland).

Variable	Unit	Name	Description
ImCattleGras	yes/no	Improved cattle kept in the grass-land	Number of improved cattle (Friesian) kept in the grassland.
IndiCattle	head	Heads of indigenous cattle	Number of indigenous cattle per household.
IndiCattleFarm	yes/no	Indigenous cattle kept in the farm	Number of indigenous cattle kept on the farm (homegarden and new farm-land).
IndiCattleGrass	yes/no	Indigenous cattle kept in the grass-land	Number of indigenous cattle kept on the grassland.
Goat	head	Heads of goats	Number of goats per household.
GoatFarm	yes/no	Goats kept in the farm	Number of goats kept on the farm (homegarden and new farmland).
GoatGrass	yes/no	Goats kept in the grassland	Number of goats kept on the grassland.
Sheep	head	Heads of sheep	Number of sheep per farm household.
SheepHome	yes/no	Sheep kept in the farm	Number of sheep kept on the farm (homegarden and new farmland).
SheepGrass	yes/no	Sheep kept in the grassland	Number of sheep kept on the grassland.
Pig	head	Heads of pigs	Number of pigs per farm household.
PigHome	yes/no	Pigs kept in the farm	Number of pigs kept on the farm (homegarden and new farmland).
PigGrass	yes/no	Pigs kept in the grassland	Number of pigs kept on the grassland.
Chicken	head	Heads of chicken	Number of chickens per farm household.
ChickenFarm	yes/no	Chicken kept in the farm	Number of chickens kept on the farm (homegarden and new farmland).
ChickenGrass	yes/no	Chicken kept in the grassland	Number of chickens kept on the grassland.
Avocado	trees	Avocado trees	Number of avocado trees *(Persea americana L.)*.
Mango	trees	Mango trees	Number of mango trees *(Mangifera indica L.).*
Guava	trees	Guava trees	Number of guava trees *(Psidium guajava L.).*
Pawpaw	trees	Pawpaw trees	Number of pawpaw trees *(Carica papaya L.).*
Jackfruit	trees	Jackfruit	Number of jackfruit trees *(Artocarpus heterophyllus)*.
OrangTangerine	trees	Orange and tangerine	Number of orange and tangerine trees *(Citrus L. spp.)*.
OtherFruit	trees	Other fruit trees	Number of other fruit trees.
Eucalyptus	trees	Eucalyptus trees	Number of eucalyptus trees *(Eucalyptus spp.)*.
SandOlive	trees	Sand olive trees	Number of sand olive *(Dodonaea angustifol.)*
Umbrella	trees	Umbrella trees	Number of umbrella tree *(Maesopsis eminii)*
SilverOak	trees	Silver oak trees	Number of silver oak *(Grevillea robusta)*

Variable	Unit	Name	Description
Pine	trees	Pine *(Pinus spp.)*	Number of pine trees *(Pinus spp.).*
OtherTree	trees	Other trees	Number of other trees.
AccForest	yes, on village land / yes, on general land / no	Access to nearby forest and woodland	If the household accesses nearby forests or woold land to cut or gather firewood.
CRC	*in situ* kib / ring kib / pit kib/ *in situ* ring pit kib / burnt / fodder / not used	Use of crop residues for composting	Crop residues used for composting via *in situ* kib = *in situ* composting in the homegarden (kibanja); ring kib = ring composting in the homegarden (kibanja); pit kib = pit composting in the homegarden (kibanja); a combination of *in situ,* ring, and pit composting; burnt on the field; used as fodder for livestock; or not used.
CRF	fodder / no fodder	Use of crop residues as fodder	Crop residues used or not used as fodder.
FW	*in situ* kib / ring kib / pit kib/ burnt / fodder / not available	Use of food waste	Food waste used in *in situ* kib = *in situ* composting in the homegarden (kibanja); ring kib = ring composting in the homegarden (kibanja); pit kib = pit composting in the homegarden (kibanja); burnt in fires; used as fodder for livestock; or the household does not have food waste (not available).
KWC	*in situ* kib / ring kib / pit kib/ burnt / fodder / not available	Use of kitchen waste	Food waste used in *in situ* kib = *in situ* composting in the homegarden (kibanja); ring kib = ring composting in the homegarden (kibanja); pit kib = pit composting in the homegarden (kibanja); burnt in fires; used as fodder for livestock; or the household does not have food waste (not available).
LM	*in situ* kib / ring kib / pit kib/ *in situ* ring pit kib / not used / not available	Use of livestock manure	Livestock manure used in *in situ* kib = *in situ* composting in the homegarden (kibanja); ring kib = ring composting in the homegarden (kibanja); pit kib = pit composting in the homegarden (kibanja); a combination of *in situ*, ring, and pit composting; or the household does not collect and use the livestock manure (not used); or the household does not have livestock manure (not available) because they do not have livestock.
LU	*in situ* kib / ring kib / pit kib/ *in situ* ring pit kib / not used / not available	Use of livestock urine	Livestock urine used in *in situ* kib = *in situ* composting in the homegarden (kibanja); ring kib = ring composting in the homegarden (kibanja); pit kib = pit composting in the homegarden (kibanja); a combination of *in situ*, ring, and pit composting; or the household does not collect and use the livestock urine (not used); or the household does not have livestock urine (not available) because they do not have livestock.

Variable	Unit	Name	Description
CA	*in situ* kib / ring kib / pit kib/ *in situ* ring pit kib / gathered in one place / toilet / not available	Use of cooking ash	Cooking ash used in *in situ* kib = *in situ* composting in the homegarden (kibanja); ring kib = ring composting in the homegarden (kibanja); pit kib = pit composting in the homegarden (kibanja); a combination of *in situ*, ring, and pit composting; or the household collects the ash in a place separated from the farmhouse and the fields; or the household does not have it (not available).
AB	*in situ* kib / ring kib / pit kib/ *in situ* ring pit kib / not used / not available	Use of animal bones	Animal bones in *in situ* kib = *in situ* composting in the homegarden (kibanja); ring kib = ring composting in the homegarden (kibanja); pit kib = pit composting in the homegarden (kibanja); a combination of *in situ*, ring, and pit composting or the household does not have it (not available).
HU	*in situ* kib / ring kib / pit kib/ *in situ* ring pit kib / not used / toilet / pesticide	Use of human urine	Human urine used in *in situ* kib = *in situ* composting in the homegarden (kibanja); ring kib = ring composting in the homegarden (kibanja); pit kib = pit composting in the homegarden (kibanja); a combination of *in situ*, ring, and pit composting; the household produces an organic pesticide with human urine; the household does not collect and use it (not used); or the household collect it in a toilet, usually a pit latrine.
HF	*in situ* kib / ring kib / pit kib/ *in situ* ring pit kib / not used / toilet	Use of human faeces	Human faeces used in *in situ* kib = *in situ* composting in the homegarden (kibanja); ring kib = ring composting in the homegarden (kibanja); pit kib = pit composting in the homegarden (kibanja); a combination of *in situ*, ring, and pit composting; or the household does not collect and use it (not used); or the household collect it in a toilet, usually a pit latrine.

Table A 7: Agricultural information.

QID	StartEarliest	StartLatest	FarmDur	TotLand	Homegarden	NewFarm	Grassland	Woodland	Coffee	Banana	Beans	Maize	Cassava
1	1989	2003	28	2.81	1.01	0.61	1.21	0.00	0.00	n.a.	n.a.	n.a.	n.a.
2	1980	2015	37	6.07	4.65	0.00	1.42	0.00	0.00	0.47	0.39	0.44	0
3	2014	2014	3	0.61	0.40	0.00	0.20	0.00	0.00	0.29	0.2	0.25	0.12
4	1970	1992	47	3.84	3.64	0.00	0.20	0.00	0.24	0.98	1.6	1.0	0.32
5	1974	2010	43	1.82	1.21	0.00	0.61	0.00	0.00	0.50	1.1	1.43	0.07
6	1991	1998	26	1.52	1.11	0.00	0.40	0.00	0.00	n.a.	n.a.	n.a.	n.a.
7	1998	1998	19	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.2	0.1	0.24
8	1977	1998	40	6.19	5.26	0.00	0.00	0.81	0.00	1.45	0.4	4.8	0.7
9	1983	2003	34	10.32	8.09	0.81	0.81	0.81	0.20	22.00	6.4	2.2	2.7

QID	StartEarliest	StartLatest	FarmDur	TotLand	Homegarden	NewFarm	Grassland	Woodland	Coffee	Banana	Beans	Maize	Cassava
10	1989	2007	28	3.84	2.02	0.00	0.81	1.21	0.30	0.31	0.26	0.06	0.06
11	1970	2012	47	5.67	4.25	0.00	0.40	1.01	0.28	0.45	0.4	0	0
12	2004	2005	13	0.81	0.81	0.00	0.00	0.00	0.00	0.55	0.26	0.01	0.63
13	1981	1993	36	1.42	0.40	1.01	0.00	0.00	0.30	0.83	0.55	0.3	0.7
14	1975	1985	42	1.74	0.12	0.12	1.21	0.00	0.05	0.09	0.108	0.096	0.78
15	1985	1985	32	1.44	1.13	0.12	0.20	0.00	0.00	0.87	0.4	0.3	0.336
16	1974	1974	43	2.43	1.42	0.40	0.40	0.20	0.03	1.68	0.62	0.07	0.17
17	2007	2007	10	0.20	0.20	0.00	0.00	0.00	0.00	0.24	0.12	0	0
18	2005	2015	12	0.47	0.40	0.00	0.00	0.00	0.00	0.27	0.24	0.1	0.028
19	2015	2015	2	0.04	0.04	0.00	0.00	0.00	0.00	0.05	0.01	0.01	0
20	1990	2014	27	5.18	2.95	0.61	1.01	0.61	1.16	0.90	1.1	1.41	0.42
21	1943	2006	74	12.34	5.06	0.00	4.05	3.24	0.00	3.91	0.95	0.72	0.4
22	1962	2015	55	6.68	4.45	1.01	0.20	0.81	0.00	6.00	0.37	0.12	0.2
23	2004	2004	13	1.01	0.91	0.10	0.00	0.00	0.00	0.27	0.36	0	0.18
24	1977	1984	40	1.84	1.62	0.00	0.12	0.12	0.14	0.09	0.3	0.4	0.72
25	2000	2015	17	11.23	3.84	0.81	1.01	5.06	0.02	1.27	0.534	0.2	0
26	1987	2015	30	0.91	0.81	0.10	0.00	0.00	0.00	0.09	0.075	0.05	0.105
27	1979	2008	38	5.87	3.24	1.62	0.00	0.81	0.00	0.61	1	0.08	0
28	1982	1990	35	0.61	0.40	0.20	0.00	0.00	0.00	0.02	0.4	0	0
29	1985	2009	32	21.35	2.14	0.40	14.57	3.76	0.07	1.82	2.96	0.228	0.24
30	1995	2013	22	5.67	3.04	1.01	0.81	0.81	0.00	0.94	0.4	0.07	0
31	2015	2016	2	1.42	1.01	0.10	0.20	0.10	0.15	0.41	0.13	0.11	0.1
32	1985	2014	32	40.60	4.05	0.00	4.05	32.38	0.00	3.20	0.8	0	0.3
33	2011	2011	6	0.40	0.40	0.00	0.00	0.00	0.00	0.11	0.06	0.005	0.005
34	1986	1998	31	3.04	2.02	0.00	1.01	0.00	0.00	2.15	0.87	0.32	0
35	1994	1994	23	0.20	0.20	0.00	0.00	0.00	0.02	0.17	0.18	0.162	0.09
36	1940	1980	77	2.59	2.63	0.00	0.12	0.00	0.00	0.10	0.17	0	0
37	1992	2014	25	1.42	1.01	0.40	0.00	0.00	0.00	0.15	0.08	0.33	0.53
38	1998	2014	19	3.84	0.81	0.81	2.02	0.00	0.00	0.42	0.17	0.26	0
39	1993	1997	24	3.84	3.44	0.40	0.00	0.00	0.07	1.85	0.45	0.144	0.09
40	1980	2014	37	6.68	n.a.	n.a.	n.a.	n.a.	0.00	3.69	0.65	0.38	0.42
41	2002	2007	15	2.02	0.81	0.00	1.21	0.00	0.00	0.25	0.16	0	0.02

QID	StartEarliest	StartLatest	FarmDur	TotLand	Homegarden	NewFarm	Grassland	Woodland	Coffee	Banana	Beans	Maize	Cassava
42	1980	1990	37	1.54	1.54	0.00	0.00	0.00	0.02	1.50	0.6	0.3	0.6
43	1988	2002	29	0.40	0.30	0.10	0.00	0.00	0.00	0.15	0.2	0.2	0
44	1998	2013	19	1.44	0.40	0.12	0.81	0.00	0.00	0.03	0.19	0.66	0.78
45	1971	1971	46	1.42	1.21	0.20	0.00	0.00	0.00	0.18	0.2	0.2	0
46	1980	1980	37	1.42	1.21	0.00	0.20	0.00	0.03	1.15	0.442	0.16	0.085
47	1992	1992	25	0.51	0.51	0.00	0.00	0.00	0.00	0.21	0.25	0.12	0.04
48	1976	2012	41	1.94	1.62	0.00	0.12	0.20	0.12	0.73	0.48	0.22	0.74
49	2002	2016	15	6.27	2.83	0.00	0.32	3.12	0.04	1.55	0.42	0.36	0
50	1971	1977	46	3.84	1.21	1.21	0.61	0.81	0.00	0.00	0.06	0.02	0.18
51	1974	1984	43	2.23	1.42	0.00	0.40	0.40	0.00	0.21	0.48	0.54	0.24
52	1998	1998	19	0.12	0.12	0.00	0.00	0.00	0.01	0.00	0.06	0.14	0
53	1987	2002	30	1.01	0.61	0.40	0.00	0.00	0.00	1.01	0.3	0.3	0.24
54	1990	1992	27	2.43	1.21	0.61	0.00	0.61	0.00	0.51	0.4	0.112	0.36
55	1975	1975	42	5.46	0.81	1.21	1.21	1.62	0.10	4.75	3.8	0.11	2.4
56	1977	1997	40	1.82	1.42	0.30	0.00	0.10	0.00	0.20	0.3	0.2	1.62
57	1979	1989	38	2.02	1.62	0.00	0.00	0.40	0.45	2.78	0.4	0.19	0.32
58	1981	2016	36	2.95	1.82	0.00	1.62	0.32	0.70	0.91	1.44	1.84	1.43
59	1980	2001	37	1.42	1.21	0.10	0.10	0.00	0.07	1.14	0.55	0.1	0.24
60	1985	1979	32	2.63	1.62	0.40	0.61	0.20	0.55	0.33	0.412	0.125	0.105
61	1988	2013	29	3.64	3.24	0.00	0.00	0.40	0.00	1.73	2.1	0.4	0.18
62	1980	1984	37	0.73	0.61	0.12	0.00	0.00	0.39	0.13	0.37	0.108	0.024
63	1987	1990	30	1.34	0.93	0.20	0.00	0.20	0.29	0.39	1.06	0.9	0.32
64	2013	2013	4	0.20	0.20	0.00	0.00	0.00	0.00	0.07	0.16	0.04	0.03
65	1987	2015	30	4.69	3.56	0.81	0.00	0.32	0.18	2.30	0.78	0.02	0.18
66	2002	2016	15	9.11	6.48	0.00	2.02	0.40	0.10	2.25	8.76	0.33	0.792
67	1985	2010	32	6.07	3.24	1.21	0.00	1.62	0.02	7.49	0.35	0.04	0
68	1976	2002	41	3.24	2.02	0.81	0.00	0.40	0.06	1.90	1.32	0	0.57
69	2002	2006	15	0.59	0.32	0.00	0.00	0.00	0.00	0.00	0.1	0	0
70	1999	2017	18	1.21	0.91	0.00	0.30	0.00	0.00	1.17	0.6	0.08	0.06
71	1988	2001	29	3.54	1.42	0.81	1.01	0.81	0.08	1.17	0.18	0.41	0.105
72	1997	2012	20	1.42	1.42	0.00	0.00	0.00	0.28	0.29	0.78	0.18	0.08
73	1980	2010	37	4.45	2.63	0.40	0.81	0.61	0.15	1.07	1.5	0.36	0.05

QID	StartEarliest	StartLatest	FarmDur	TotLand	Homegarden	NewFarm	Grassland	Woodland	Coffee	Banana	Beans	Maize	Cassava
74	1970	1970	47	0.81	0.71	0.10	0.00	0.00	0.00	0.10	0.4	0.1	0.06
75	1985	1995	32	1.62	1.42	0.00	0.00	0.00	0.01	1.13	0.44	0.1	0
76	1976	1976	41	0.40	0.32	0.00	0.00	0.08	0.00	0.22	0.22	0.06	0.15
77	1975	1975	42	0.42	0.32	0.12	0.00	0.00	0.00	0.18	0.1	0.06	0.02
78	1980	1999	37	1.01	0.81	0.00	0.00	0.20	0.00	0.33	0.39	0.24	0
79	1978	1980	39	2.45	1.94	0.40	0.12	0.00	0.00	1.03	0.8	0.35	0.22
80	1981	2009	36	5.26	3.64	0.00	0.00	1.62	0.00	1.11	0.16	0.1	0.3
81	1987	1987	30	0.81	0.81	0.00	0.00	0.00	0.00	4.40	0.9	1.2	3.8
82	1966	1973	51	11.74	11.74	0.00	0.00	0.00	0.00	6.70	4.5	3.5	1.052
83	1985	1985	32	0.92	0.71	0.40	0.00	0.00	0.00	0.14	0.2	0.2	0.15
84	1970	1970	47	0.81	0.81	0.00	0.00	0.00	0.00	0.70	0.22	0.12	0.21
85	1994	1994	23	1.21	1.21	0.00	0.00	0.00	0.00	0.29	0.11	0.14	0.022
86	1985	2004	32	3.34	2.83	0.20	0.00	0.40	0.00	2.39	1.1	1	0
87	2003	2003	14	0.20	0.20	0.00	0.00	0.00	0.00	0.04	0.04	0.02	0.035
88	1979	1979	38	0.81	0.81	0.00	0.00	0.00	0.00	0.15	0.06	0.02	0
89	2000	2000	17	2.02	2.02	0.00	0.00	0.00	0.00	3.16	0.72	1.13	0.01
90	1997	1997	20	0.12	0.12	0.00	0.00	0.00	0.00	0.03	0.32	0.06	0
91	1981	1981	36	0.40	0.40	0.00	0.00	0.00	0.12	0.28	0.07	0.17	0.07
92	2015	2015	2	0.81	0.81	0.00	0.00	0.00	0.23	0.30	0.12	0.24	0.24
93	1984	2010	33	4.25	3.14	0.40	0.00	0.71	0.53	3.38	0.95	0.8	0.21
94	1994	2005	23	4.45	1.01	2.43	0.81	0.20	0.33	1.84	1	0.6	0.18
95	1986	1986	31	0.40	0.40	0.00	0.00	0.00	0.10	0.29	0.24	0.06	0.45
96	1997	1997	20	0.32	0.32	0.00	0.00	0.00	0.04	0.05	0.012	0.015	0
97	2000	2000	17	2.43	2.23	0.20	0.00	0.00	0.37	8.70	0.84	0.64	0.48
98	1996	2008	21	0.20	0.20	0.00	0.00	0.00	0.10	0.22	0.03	0.04	0.04
99	2001	2013	16	1.13	0.93	0.12	0.00	0.00	0.60	1.75	0.36	0.5	0
100	1990	1990	27	1.42	1.21	0.20	0.00	0.00	0.08	0.80	0.48	1.2	0.5
101	1974	1974	43	0.40	0.40	0.00	0.00	0.00	0.00	0.17	0.16	0.18	0.3
102	1994	1996	23	1.01	0.81	0.20	0.00	0.00	0.03	0.28	0.1	0.24	0.08
103	2001	2004	16	0.73	0.73	0.00	0.00	0.00	0.06	0.38	0.14	0.12	0.144
104	2002	2002	15	0.20	0.20	0.00	0.00	0.00	0.23	0.07	0.2	0.1	0.3
105	n.a.	n.a.	n.a.	0.42	0.32	0.12	0.00	0.00	0.03	0.07	0.12	0.2	0.08

QID	StartEarliest	StartLatest	FarmDur	TotLand	Homegarden	NewFarm	Grassland	Woodland	Coffee	Banana	Beans	Maize	Cassava
106	1978	1981	39	1.82	1.01	0.40	0.40	0.00	0.56	1.21	0.42	0.12	0
107	1997	1999	20	2.43	1.92	0.51	0.00	0.00	0.11	1.72	0.6	0.8	0.06
108	1992	2012	25	3.10	3.08	0.00	0.00	0.00	0.06	1.27	0.12	0.1	0.2
109	1979	2017	38	7.00	4.45	0.81	0.12	1.50	4.00	27.45	0.6	0.8	1.2
110	1983	2015	34	3.34	1.62	0.81	0.51	0.40	0.86	4.07	0.7	0.6	0.18
111	2015	2016	2	1.01	0.81	0.20	0.00	0.00	0.27	4.80	0.63	2.4	1.44
112	1996	2015	21	2.13	1.62	0.00	0.40	0.10	0.20	3.02	0.8	0.1	0.36
113	1970	2005	47	2.75	2.43	0.00	0.32	0.00	1.60	5.12	0.36	0.22	0.09
114	2006	2009	11	1.74	1.74	0.00	0.00	0.00	1.50	10.00	1.08	1.4	2.4
115	1988	1997	29	2.23	2.02	0.20	0.00	0.00	2.08	5.04	0.8	1	0.12
116	1985	1985	32	3.56	2.75	0.81	0.00	0.00	2.10	2.43	1.62	1.26	0.16
117	1959	1997	58	14.49	8.50	0.00	4.78	1.21	3.44	25.60	0.8	0.432	0
118	2012	2012	5	1.01	1.01	0.00	0.00	0.00	0.20	1.06	0.5	0.3	0
119	2010	2010	7	0.12	0.12	0.00	0.00	0.00	0.19	0.92	0.36	0.3	0.6
120	1989	2013	28	4.05	1.62	0.81	0.00	1.62	2.44	1.33	0.4	0.6	0.06
121	2003	2003	14	0.32	0.32	0.00	0.00	0.00	0.07	0.00	0.1	0.06	0.05
122	1994	2015	23	3.97	2.55	0.00	0.00	1.42	0.24	9.80	1.82	0.72	0.64
123	1989	2016	28	2.63	1.62	0.61	0.00	0.40	0.14	2.71	0.48	0.5	0.06
124	1977	1985	40	4.65	2.83	0.00	0.81	1.01	0.00	3.95	1.68	0.5	0.12
125	1993	2015	24	1.82	1.21	0.00	0.40	0.20	0.00	3.62	0.45	0.18	0.18
126	2015	2015	2	1.01	1.01	0.00	0.00	0.00	0.20	0.61	0.7	0.3	0.06
127	2010	2017	7	1.13	1.01	0.12	0.00	0.00	0.13	0.90	1.42	0.2	0.168
128	2001	2016	16	0.91	1.01	0.00	0.00	0.00	0.32	1.80	1.08	0.77	1.01
129	1993	2011	24	6.54	4.65	0.00	1.74	0.40	0.55	0.63	0.73	2.45	0.105
130	2006	2009	11	2.43	2.43	0.00	0.00	0.00	0.13	1.61	0.7	0.36	0.4
131	1982	2015	35	9.21	6.27	2.02	0.00	0.81	1.11	9.68	3	2.16	3
132	1990	2000	27	2.75	2.14	0.00	0.00	0.61	0.21	0.88	0.48	0.3	0.36
133	1973	2011	44	6.37	5.16	0.40	0.81	0.00	0.13	1.53	0.2	0	0.9
134	2008	2016	9	0.73	0.73	0.00	0.00	0.00	0.26	0.22	0.84	0.08	0.06
135	1987	1999	30	1.01	0.71	0.00	0.20	0.10	0.04	1.22	0.28	0	0.06
136	1994	2002	23	2.02	2.02	0.00	0.00	0.00	0.29	1.52	1.92	0.1	0.96
137	1994	2016	23	3.84	2.23	0.61	0.81	0.20	0.00	13.09	2.42	0.7	0.03

QID	StartEarliest	StartLatest	FarmDur	TotLand	Homegarden	NewFarm	Grassland	Woodland	Coffee	Banana	Beans	Maize	Cassava
138	2001	2016	16	15.78	10.12	0.00	0.00	5.67	0.02	8.00	18.36	5.6	0.64
139	1995	2014	22	2.02	2.02	0.00	0.00	0.00	0.00	1.00	0.5	0.38	0.6
140	1994	2006	23	9.51	3.24	0.61	4.05	1.62	0.00	13.15	3.6	4.6	0
141	1994	2015	23	1.82	1.62	0.20	0.00	0.00	0.00	0.77	0.6	0.9	0.03
142	1995	1999	22	0.93	0.93	0.00	0.00	0.00	0.71	0.34	0.08	0.2	0
143	1992	2007	25	2.43	1.42	1.01	0.00	0.00	0.26	2.35	0.99	0	0
144	2015	2015	2	0.11	0.12	0.00	0.00	0.00	0.00	0.00	0.1	0.12	0
145	2002	2017	15	2.06	1.54	0.32	0.32	0.00	0.00	n.a.	0.3	0.6	0
146	2000	2000	17	0.97	1.01	0.00	0.00	0.00	0.08	0.14	0.77	0.28	0
147	2007	2001	10	0.40	0.40	0.00	0.00	0.00	0.00	0.21	0.15	0	0
148	1965	1965	52	3.24	2.23	0.40	0.40	0.20	0.00	1.60	0.2	0.36	0.135
149	1999	2000	18	4.57	3.24	0.40	0.12	0.81	0.07	5.15	2.9	0.4	0.18
150	1996	2013	21	2.83	1.82	1.01	0.00	0.00	0.33	3.02	0.6	0	0.6

Table A-7 cont.: Agricultural information.

QID	Avocado	Mango	Guava	Pawpaw	Jackfruit	OrangTangerine	OtherFruit	Eucalyptus	Sand Olive	Umbrella	SilverOak	Pine	OtherTree
1	0	0	0	0	0	0	0	0	0	0	0	0	700
2	0	0	0	0	0	0	0	0	0	0	0	0	6000
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	15	0	0	0	5	0	0	300	0	20	0	0	0
5	14	1	0	0	3	0	0	100	3	8	0	0	6
6	0	4	0	3	0	0	0	200	0	0	0	0	0
7	1	3	1	1	0	0	1	0	3	0	0	0	0
8	20	10	0	0	0	0	0	2000	0	0	0	0	0
9	12	3	4	0	0	0	0	1000	25	0	150	0	10
10	15	10	0	5	0	0	0	2100	50	0	0	0	0
11	7	5	0	0	0	1	0	250	20	30	0	0	79
12	4	1	0	2	0	0	0	0	0	0	0	0	0
13	50	20	0	0	1	0	0	0	1	0	0	0	0
14	3	2	0	2	0	0	2	10	15	1	0	0	0
15	4	5	6	2	0	0	0	0	10	5	0	0	0

QID	Avocado	Mango	Guava	Pawpaw	Jackfruit	OrangTangerine	OtherFruit	Eucalyptus	Sand Olive	Umbrella	SilverOak	Pine	OtherTree
16	2	5	5	15	0	0	4	50	10	100	5	0	16
17	0	1	0	1	0	0	1	0	0	0	1	0	0
18	2	0	0	3	0	0	0	0	0	6	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0
20	10	7	0	2	0	2	3	5000	80	0	30	0	69
21	8	10	1	10	0	2	2	5	30	80	0	2000	1
22	4	10	0	0	0	0	3	400	0	10	0	0	4
23	2	1	0	2	0	0	3	0	25	25	0	0	0
24	10	6	0	0	2	0	0	70	0	30	0	0	0
25	40	5	0	8	0	0	0	8000	50	300	50	1000	600
26	2	2	0	6	0	0	1	0	0	4	1	0	0
27	4	2	0	0	0	2	2	3000	0	50	0	0	20
28	2	2	0	0	0	2	0	0	0	1	2	0	0
29	10	6	0	12	0	0	1	0	0	32	0	0	200
30	2	2	2	4	0	0	1	0	5	5	0	0	0
31	0	0	1	5	0	1	1	20	7	1	0	0	1
32	500	500	10	50	100	51	70	4000	200	1000	300	4000	500
33	2	10	0	0	0	0	0	0	0	0	0	0	0
34	3	2	0	5	1	0	0	0	2	0	0	0	0
35	1	1	0	0	3	0	0	0	0	1	0	0	0
36	6	0	0	0	2	0	0	0	0	0	0	0	0
37	1	0	0	4	1	0	0	0	0	0	0	0	0
38	0	3	1	3	0	0	0	0	30	0	0	0	0
39	3	1	0	2	2	0	0	0	7	0	0	0	0
40	5	8	3	10	0	5	8	500	200	500	0	0	0
41	3	9	0	0	2	7	1	0	0	0	0	0	20
42	4	0	0	3	0	0	1	0	6	3	0	0	0
43	1	4	0	1	1	2	0	0	0	0	0	0	0
44	2	2	0	0	2	3	0	0	0	0	0	0	2
45	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
46	2	3	0	8	0	2	2	100	0	0	0	0	0
47	1	1	1	0	0	0	0	0	0	0	0	0	0

QID	Avocado	Mango	Guava	Pawpaw	Jackfruit	OrangTangerine	OtherFruit	Eucalyptus	Sand Olive	Umbrella	SilverOak	Pine	OtherTree
48	4	5	0	5	1	0	7	100	10	7	18	0	5
49	60	10	7	6	0	0	0	0	0	0	0	0	5
50	8	5	2	3	0	4	1	100	15	15	0	0	0
51	4	5	0	4	0	0	8	500	800	10	5	0	20
52	1	2	0	1	0	0	0	0	20	0	0	0	0
53	3	4	2	5	0	0	0	0	5	5	0	0	2
54	6	0	0	5	0	2	5	250	20	0	0	0	0
55	3	15	0	3	0	3	0	7500	0	0	0	2500	0
56	200	10	2	80	0	0	6	300	50	50	0	0	0
57	4	12	0	60	0	2	3	9830	50	120	0	0	0
58	20	10	3	3	0	0	6	500	20	12	0	0	10
59	3	0	1	3	0	0	1	0	0	0	0	0	0
60	10	10	2	0	0	0	3	0	20	20	5	0	5
61	1	5	4	10	0	0	0	500	10	100	10	0	0
62	2	4	0	3	0	0	0	0	4	0	0	0	0
63	5	5	0	1	0	0	2	200	5	0	20	0	75
64	7	1	1	0	0	0	0	50	2	0	0	0	0
65	30	5	0	20	0	0	1	100	0	100	0	0	0
66	50	10	0	15	0	0	3	7000	20	10	0	0	0
67	5	3	1	3	0	0	3	2500	10	2	2	0	2
68	1	4	0	7	0	1	1	1000	8	1	0	0	2
69	0	0	0	0	0	0	0	0	0	0	0	0	0
70	2	3	1	8	0	0	0	0	20	7	0	0	15
71	5	4	0	0	0	1	1	3000	20	6	0	0	0
72	0	5	0	4	0	0	0	0	3	5	0	0	0
73	5	1	0	5	0	0	1	1500	0	10	0	0	0
74	1	3	2	0	0	1	1	100	3	1	5	0	0
75	1	1	0	0	0	0	0	50	0	0	0	0	0
76	0	2	0	2	0	0	0	10	10	5	0	0	1
77	1	0	0	1	0	1	0	0	0	0	1	0	2
78	12	1	0	6	3	1	3	100	0	6	0	0	0
79	10	6	0	5	0	0	1	0	4	4	4	0	5

QID	Avocado	Mango	Guava	Pawpaw	Jackfruit	OrangTangerine	OtherFruit	Eucalyptus	Sand Olive	Umbrella	SilverOak	Pine	OtherTree
80	50	5	1	5	0	0	0	5000	50	5	20	0	0
81	5	1	0	4	0	0	5	0	10	2	0	0	0
82	8	5	0	4	0	0	6	0	25	12	0	0	4
83	2	2	1	2	0	0	0	0	0	5	0	0	0
84	7	4	0	5	0	0	5	0	10	9	0	0	7
85	4	2	0	4	0	0	1	0	0	10	0	0	0
86	6	10	7	20	6	0	8	0	3	15	6	0	0
87	5	3	0	1	1	0	0	0	0	0	0	0	0
88	5	5	2	2	1	0	1	0	6	5	12	0	1
89	3	0	0	3	5	2	30	0	0	0	0	0	23
90	0	1	0	3	1	0	0	0	0	0	0	0	0
91	0	0	0	2	0	0	0	0	0	0	0	0	0
92	0	0	0	3	0	0	6	0	8	12	2	0	0
93	8	3	10	12	1	5	3	800	20	250	4	0	0
94	10	6	5	5	1	0	3	1000	0	10	0	0	0
95	0	0	0	0	0	0	6	0	3	5	0	0	8
96	0	0	0	1	0	0	0	0	0	2	0	0	0
97	15	4	0	6	0	0	5	0	6	10	2	0	1
98	5	1	0	3	1	0	2	0	0	0	0	0	0
99	10	3	0	8	0	0	0	0	0	10	0	0	0
100	2	1	0	3	0	0	3	0	0	10	0	0	1
101	6	5	0	5	3	0	0	0	6	4	0	0	0
102	5	1	0	4	0	0	4	0	0	0	0	0	0
103	0	0	0	0	0	0	0	0	0	10	0	0	0
104	0	2	0	3	0	0	1	0	0	0	0	0	0
105	1	2	0	2	0	2	0	0	10	2	0	0	0
106	5	4	0	7	0	0	2	0	3	0	0	0	2
107	1	2	1	1	0	0	0	0	0	0	0	0	0
108	30	15	6	20	0	2	0	0	0	80	40	0	5
109	30	30	0	10	0	0	25	2000	50	115	0	0	12
110	20	30	15	20	2	6	7	4000	20	100	50	0	100
111	5	2	0	4	0	0	6	0	0	20	0	0	1

QID	Avocado	Mango	Guava	Pawpaw	Jackfruit	OrangTangerine	OtherFruit	Eucalyptus	Sand Olive	Umbrella	SilverOak	Pine	OtherTree
112	5	4	4	3	0	0	0	1000	20	10	8	0	0
113	0	4	0	0	0	0	0	500	0	0	0	0	0
114	20	6	0	4	0	0	4	0	4	0	0	0	0
115	6	4	3	4	0	3	1	0	5	6	15	0	0
116	4	5	0	0	0	1	0	0	0	8	1	0	2
117	25	10	0	5	0	0	10	0	20	1000	20	0	10
118	1	1	0	2	1	0	0	0	0	0	50	0	0
119	3	0	0	1	0	0	0	0	0	0	0	0	0
120	6	4	3	10	4	2	1	5000	2	6	0	0	0
121	1	0	0	1	0	0	0	0	0	0	0	0	0
122	8	10	0	0	0	0	9	2500	20	60	0	0	8
123	10	8	0	30	0	1	0	5000	0	26	0	0	0
124	8	14	5	0	0	0	0	1500	0	20	15	105	0
125	2	2	0	1	0	0	0	50	0	50	0	0	0
126	3	1	1	0	0	0	0	0	0	2	0	0	0
127	1	1	0	2	0	1	0	0	0	4	0	0	0
128	0	4	0	5	0	0	16	0	0	15	10	0	4
129	25	7	0	10	0	1	1	0	20	20	50	0	5
130	16	0	0	0	0	0	0	0	0	0	0	0	0
131	20	5	0	6	0	4	0	6000	0	100	200	0	2
132	2	4	0	0	0	0	0	6000	15	5	0	0	0
133	0	7	0	0	0	0	0	0	12	0	0	0	0
134	3	1	0	0	0	0	1	0	0	6	0	0	3
135	2	2	1	0	0	0	0	100	3	8	0	0	0
136	7	10	3	10	0	0	0	0	5	20	20	0	40
137	13	6	0	6	0	0	4	1000	30	0	10	0	10
138	20	0	0	10	7	100	0	10	10	300	0	6000	0
139	4	20	4	0	0	0	0	0	10	20	0	0	0
140	18	6	0	8	0	0	0	1000	30	18	0	0	20
141	4	2	1	5	1	0	2	0	5	20	0	0	0
142	0	3	0	0	0	0	0	0	5	0	0	0	12
143	1	3	0	0	0	0	0	0	6	17	0	0	0

QID	Avocado	Mango	Guava	Pawpaw	Jackfruit	OrangTangerine	OtherFruit	Eucalyptus	Sand Olive	Umbrella	SilverOak	Pine	OtherTree
144	0	0	0	0	0	0	0	0	0	0	0	0	0
145	10	14	7	10	4	0	0	0	2306	0	0	0	0
146	6	5	0	5	0	0	2	10	3	2	0	0	0
147	0	2	0	1	0	0	0	0	2	3	0	0	0
148	0	2	1	3	0	0	0	500	10	10	0	0	0
149	4	8	0	30	0	0	6	150	20	12	1	0	2
150	4	5	3	0	1	0	0	0	10	15	0	0	0

Table A-7 cont.: Agricultural information.

QID	AccForest	TotTLU	TLUFarm	TLUGrass	ImCattle	ImCattleFarm	ImCattleGras	IndiCattle	IndiCattleFarm	IndiCattleGrass
1	yes, on village land.	2.67	0.07	2.60	0	no	no	2	no	yes
2	no	34.26	1.66	32.60	0	no	no	24	no	yes
3	yes, on general land.	0.27	0.27	0.00	0	no	no	0	no	no
4	no	4.09	0.09	4.00	0	no	no	0	no	no
5	Old template.	0.61	0.61	0.00	0	no	no	0	no	no
6	no	9.26	2.06	7.20	0	no	no	4	no	yes
7	yes, on general land.	1.41	1.41	0.00	0	no	no	0	no	no
8	yes, on village land.	1.05	1.05	0.00	0	no	no	0	no	no
9	yes, on village land.	54.50	2.50	52.00	0	no	no	40	no	yes
10	no	3.82	1.22	2.60	2	no	yes	0	no	no
11	yes, on general land.	19.76	0.26	19.50	0	no	no	15	no	yes
12	yes, on village land.	0.60	0.60	0.00	0	no	no	0	no	no
13	yes, on general land.	5.20	5.20	0.00	0	no	no	4	yes	no
14	yes, on village land.	0.05	0.05	0.00	0	no	no	0	no	no
15	yes, on general land.	0.41	0.41	0.00	0	no	no	0	no	no
16	no	6.65	6.65	0.00	0	no	no	5	yes	no
17	yes, on general land.	2.00	2.00	0.00	0	no	no	0	no	no
18	yes, on village land.	8.57	8.57	0.00	0	no	no	5	yes	no
19	yes, on village land.	0.02	0.02	0.00	0	no	no	0	no	no
20	no	0.00	0.00	0.00	0	no	no	0	no	no
21	yes, on village land.	11.72	11.72	0.00	3	yes	no	3	yes	no

QID	AccForest	TotTLU	TLUFarm	TLUGrass	ImCattle	ImCattleFarm	ImCattleGras	IndiCattle	IndiCattleFarm	IndiCattleGrass
22	no	2.50	2.50	0.00	1	yes	no	0	no	no
23	yes, on general land.	0.05	0.05	0.00	0	no	no	0	no	no
24	no	0.85	0.85	0.00	0	no	no	0	no	no
25	yes, on general land.	18.00	18.00	0.00	0	no	no	12	yes	no
26	yes, on general land.	0.00	0.00	0.00	0	no	no	0	no	no
27	yes, on village land.	3.32	3.32	0.00	1	yes	no	0	no	no
28	yes, on village land.	0.41	0.41	0.00	0	no	no	0	no	no
29	yes, on village land.	14.51	0.11	14.40	0	no	no	10	no	yes
30	yes, both.	1.71	1.71	0.00	1	yes	no	0	no	no
31	yes, on general land.	1.34	1.34	0.00	1	yes	no	0	no	no
32	yes, on village land.	20.10	0.00	20.10	0	no	no	10	no	yes
33	yes, on village land.	0.02	0.02	0.00	0	no	no	0	no	no
34	yes, on village land.	1.20	1.20	0.00	0	no	no	0	no	no
35	yes, on village land.	1.22	1.22	0.00	0	no	no	0	no	no
36	yes, on village land.	0.03	0.03	0.00	0	no	no	0	no	no
37	yes, on village land.	0.06	0.06	0.00	0	no	no	0	no	no
38	yes, on village land.	1.20	1.20	0.00	0	no	no	0	no	no
39	yes, on village land.	1.67	1.67	0.00	0	no	no	0	no	no
40	no	13.07	0.07	13.00	0	no	no	10	no	yes
41	yes, on village land.	0.00	0.00	0.00	0	no	no	0	no	no
42	yes, on village land.	0.82	0.82	0.00	0	no	no	0	no	no
43	yes, on village land.	0.00	0.00	0.00	0	no	no	0	no	no
44	yes, on village land.	0.12	0.12	0.00	0	no	no	0	no	no
46	yes, on general land.	0.21	0.21	0.00	0	no	no	0	no	no
47	yes, both.	0.44	0.44	0.00	0	no	no	0	no	no
48	no	1.68	0.08	1.60	0	no	no	0	no	no
49	yes, on village land.	36.41	0.01	36.40	0	no	no	28	no	yes
50	no	2.32	2.32	0.00	0	no	no	1	yes	no
51	no	0.05	0.05	0.00	0	no	no	0	no	no
52	yes, on village land.	0.60	0.60	0.00	0	no	no	0	no	no
53	no	0.60	0.60	0.00	0	no	no	0	no	no
54	no	1.02	1.02	0.00	0	no	no	0	no	no

QID	AccForest	TotTLU	TLUFarm	TLUGrass	ImCattle	ImCattleFarm	ImCattleGras	IndiCattle	IndiCattleFarm	IndiCattleGrass
55	yes, on village land.	1.24	1.24	0.00	0	no	no	0	no	no
56	yes, both.	0.00	0.00	0.00	0	no	no	0	no	no
57	no	7.56	7.56	0.00	0	no	no	5	yes	no
58	no	22.84	0.04	22.80	0	no	no	16	no	yes
59	yes, both.	0.47	0.47	0.00	0	no	no	0	no	no
60	yes, on general land.	3.00	3.00	0.00	2	yes	no	0	no	no
61	yes, on village land.	21.51	2.01	19.50	0	no	no	15	no	yes
62	yes, on general land.	0.62	0.62	0.00	0	no	no	0	no	no
63	no	0.03	0.03	0.00	0	no	no	0	no	no
64	no	1.21	1.21	0.00	0	no	no	0	no	no
65	yes, on general land.	1.24	1.24	0.00	0	no	no	0	no	no
66	yes, on general land.	15.20	13.20	2.00	0	no	no	10	yes	no
67	no	5.65	0.45	5.20	0	no	no	4	no	yes
68	yes, on village land.	7.50	1.00	6.50	0	no	no	5	no	yes
69	yes, on village land.	0.02	0.02	0.00	0	no	no	0	no	no
70	yes, on general land.	2.00	2.00	0.00	0	no	no	0	no	no
71	yes, on village land.	2.00	1.40	0.60	0	no	no	0	no	no
72	yes, on general land.	10.05	10.05	0.00	0	no	no	0	no	no
73	no	24.00	24.00	0.00	0	no	no	10	yes	no
74	yes, on village land.	0.61	0.21	0.40	0	no	no	0	no	no
75	yes, on village land.	0.43	0.43	0.00	0	no	no	0	no	no
76	yes, on general land.	0.61	0.61	0.00	0	no	no	0	no	no
77	no	0.00	0.00	0.00	0	no	no	0	no	no
78	no	0.40	0.40	0.00	0	no	no	0	no	no
79	no	1.08	1.08	0.00	0	no	no	0	no	no
80	no	2.70	2.70	0.00	0	no	no	0	no	no
81	yes, on general land.	1.04	1.04	0.00	0	no	no	0	no	no
82	no	0.60	0.60	0.00	0	no	no	0	no	no
83	no	0.00	0.00	0.00	0	no	no	0	no	no
84	no	0.86	0.86	0.00	0	no	no	0	no	no
85	no	0.83	0.83	0.00	0	no	no	0	no	no
86	no	1.24	1.24	0.00	0	no	no	0	no	no

QID	AccForest	TotTLU	TLUFarm	TLUGrass	ImCattle	ImCattleFarm	ImCattleGras	IndiCattle	IndiCattleFarm	IndiCattleGrass
87	yes, on general land.	0.01	0.01	0.00	0	no	no	0	no	no
88	no	0.20	0.20	0.00	0	no	no	0	no	no
89	yes, on general land.	0.62	0.62	0.00	0	no	no	0	no	no
90	yes, on village land.	0.05	0.05	0.00	0	no	no	0	no	no
91	no	0.00	0.00	0.00	0	no	no	0	no	no
92	no	0.02	0.02	0.00	0	no	no	0	no	no
93	no	3.95	3.95	0.00	0	no	no	0	no	no
94	yes, on village land.	1.03	1.03	0.00	0	no	no	0	no	no
95	no	0.00	0.00	0.00	0	no	no	0	no	no
96	yes, on village land.	0.22	0.22	0.00	0	no	no	0	no	no
97	yes, on village land.	0.04	0.04	0.00	0	no	no	0	no	no
98	yes, on general land.	0.03	0.00	0.00	0	no	no	0	no	no
99	no	0.25	0.25	0.00	0	no	no	0	no	no
100	no	0.27	0.27	0.00	0	no	no	0	no	no
101	no	0.21	0.21	0.00	0	no	no	0	no	no
102	yes, on village land.	0.06	0.06	0.00	0	no	no	0	no	no
103	yes, on general land.	0.00	0.00	0.00	0	no	no	0	no	no
104	yes, on village land.	0.63	0.63	0.00	0	no	no	0	no	no
105	no	0.61	0.61	0.00	0	no	no	0	no	no
106	yes, on general land.	0.04	0.04	0.00	0	no	no	0	no	no
107	yes, on general land.	4.04	4.04	0.00	2	yes	no	0	no	no
108	no	1.45	1.45	0.00	0	no	no	0	no	no
109	no	28.47	2.47	26.00	0	no	no	20	no	yes
110	no	0.02	0.02	0.00	0	no	no	0	no	no
111	yes, on village land.	0.83	0.83	0.00	0	no	no	0	no	no
112	no	0.87	0.87	0.00	0	no	no	0	no	no
113	yes, on village land.	6.47	6.47	0.00	0	no	no	4	yes	no
114	yes, on general land.	1.44	1.44	0.00	0	no	no	0	no	no
115	yes, on general land.	1.44	1.44	0.00	0	no	no	0	no	no
116	no	2.00	2.00	0.00	0	no	no	0	no	no
117	no	126.10	0.00	126.10	0	no	no	97	no	yes
118	yes, both.	0.00	0.00	0.00	0	no	no	0	no	no

QID	AccForest	TotTLU	TLUFarm	TLUGrass	ImCattle	ImCattleFarm	ImCattleGras	IndiCattle	IndiCattleFarm	IndiCattleGrass
119	yes, on village land.	0.60	0.60	0.00	0	no	no	0	no	no
120	no	81.90	0.10	81.80	0	no	no	62	no	yes
121	yes, on village land.	0.02	0.02	0.00	0	no	no	0	no	no
122	no	0.07	0.07	0.00	0	no	no	0	no	no
123	no	2.24	2.24	0.00	0	no	no	0	no	no
124	no	1.14	1.14	0.00	0	no	no	0	no	no
125	no	0.41	0.41	0.00	0	no	no	0	no	no
126	yes, on general land.	0.21	0.21	0.00	0	no	no	0	no	no
127	no	0.24	0.24	0.00	0	no	no	0	no	no
128	no	0.00	0.00	0.00	0	no	no	0	no	no
129	no	2.72	2.72	0.00	1	yes	no	0	no	no
130	yes, on general land.	1.60	1.60	0.00	0	no	no	0	no	no
131	no	30.20	2.90	27.30	2	yes	no	15	no	yes
132	no	0.00	0.00	0.00	0	no	no	0	no	no
133	yes, both.	0.00	0.00	0.00	0	no	no	0	no	no
134	yes, on general land.	0.00	0.00	0.00	0	no	no	0	no	no
135	no	0.04	0.04	0.00	0	no	no	0	no	no
136	no	0.40	0.40	0.00	0	no	no	0	no	no
137	yes, on general land.	10.52	0.12	10.40	0	no	no	8	no	yes
138	no	0.42	0.42	0.00	0	no	no	0	no	no
139	yes, on general land.	2.75	2.75	0.00	0	no	no	0	no	no
140	no	87.03	0.00	87.03	6	no	yes	60	no	yes
141	yes, on general land.	0.45	0.45	0.00	0	no	no	0	no	no
142	no	0.00	0.00	0.00	0	no	no	0	no	no
143	no	0.12	0.12	0.00	0	no	no	0	no	no
144	yes, on general land.	0.00	0.00	0.00	0	no	no	0	no	no
145	no	0.00	0.00	0.00	0	no	no	0	no	no
146	yes, on village land.	0.00	0.00	0.00	0	no	no	0	no	no
147	no	0.85	0.85	0.00	0	no	no	0	no	no
148	no	0.20	0.20	0.00	0	no	no	0	no	no
149	no	0.75	0.75	0.00	0	no	no	0	no	no
150	yes, both.	1.20	1.20	0.00	0	no	no	0	no	no

Table A-7 cont.: Agricultural information.

QID	Goat	GoatFarm	GoatGrass	Goat	Sheep	SheepHome	SheepGrass	Pig	PigHome	PigGrass	Chicken	ChickenFarm	ChickenGrass
1	0	no	no	0	0	no	No	0	no	no	7	yes	no
2	6	yes	no	6	7	no	Yes	2	yes	no	6	yes	no
3	1	yes	no	1	0	no	No	0	no	no	7	yes	no
4	20	no	yes	20	0	no	No	0	no	no	9	yes	no
5	0	no	no	0	3	yes	No	0	no	no	1	yes	no
6	10	yes	yes	10	0	no	No	0	no	no	6	yes	no
7	7	yes	no	7	0	no	No	0	no	no	1	yes	no
8	5	yes	no	5	0	no	No	0	no	no	5	yes	no
9	12	yes	no	12	0	no	No	0	no	no	10	yes	no
10	4	yes	no	4	2	yes	No	0	no	no	2	yes	no
11	0	no	no	0	0	no	No	1	yes	no	6	yes	no
12	3	yes	no	3	0	no	No	0	no	no	0	yes	no
13	0	no	no	0	0	no	No	0	no	no	0	no	no
14	0	no	no	0	0	no	No	0	no	no	5	yes	no
15	2	yes	no	2	0	no	No	0	no	no	1	yes	no
16	0	no	no	0	0	no	No	0	no	no	15	yes	no
17	9	yes	no	9	0	no	no	1	yes	no	0	no	no
18	10	yes	no	10	0	no	no	0	no	no	7	yes	no
19	0	no	no	0	0	no	no	0	no	no	2	yes	no
20	0	no	no	0	0	no	no	0	no	no	0	no	no
21	16	yes	no	16	0	no	no	3	yes	no	12	yes	no
22	5	yes	no	5	0	no	no	1	yes	no	0	no	no
23	0	no	no	0	0	no	no	0	no	no	5	yes	no
24	4	yes	no	4	0	no	no	0	no	no	5	yes	no
25	0	no	no	0	0	no	no	12	yes	no	0	no	no
26	0	no	no	0	0	no	no	0	no	no	0	no	no
27	5	yes	no	5	0	no	no	5	yes	no	2	yes	no
28	1	yes	no	1	0	no	no	1	yes	no	1	yes	no
29	2	no	yes	2	5	no	yes	0	no	no	11	yes	no
30	2	yes	no	2	0	no	no	0	no	no	1	yes	no
31	0	no	no	0	0	no	no	0	no	no	4	yes	no

QID	Goat	GoatFarm	GoatGrass	Goat	Sheep	SheepHome	SheepGrass	Pig	PigHome	PigGrass	Chicken	ChickenFarm	ChickenGrass
32	32	no	no	32	0	no	no	2	no	yes	30	no	yes
33	0	no	no	0	0	no	no	0	no	no	2	yes	no
34	0	no	no	0	0	no	no	0	no	no	120	yes	no
35	6	yes	no	6	0	no	no	0	no	no	2	yes	no
36	0	no	no	0	0	no	no	0	no	no	3	yes	no
37	0	no	no	0	0	no	no	0	no	no	6	yes	no
38	6	yes	no	6	0	no	no	0	no	no	0	no	no
39	7	yes	no	7	1	yes	no	0	no	no	7	yes	no
40	0	no	no	0	0	no	no	0	no	no	7	yes	no
41	0	no	no	0	0	no	no	0	no	no	0	no	no
42	4	yes	no	4	0	no	no	0	no	no	2	yes	no
43	0	no	no	0	0	no	no	0	no	no	0	no	no
44	0	no	no	0	0	no	no	0	no	no	12	yes	no
45	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
46	1	yes	no	1	0	no	no	0	no	no	1	yes	no
47	2	yes	no	2	0	no	no	0	no	no	4	yes	no
48	8	no	yes	8	0	no	no	0	no	no	8	yes	no
49	0	no	no	0	0	no	no	0	yes	no	1	yes	no
50	2	yes	no	2	3	yes	no	0	no	no	2	yes	no
51	0	no	no	0	0	no	no	0	no	no	5	yes	no
52	2	yes	no	2	0	no	no	1	yes	no	0	yes	no
53	3	yes	no	3	0	no	no	0	no	no	0	no	no
54	5	yes	no	5	0	no	no	0	no	no	2	yes	no
55	6	yes	no	6	0	no	no	0	no	no	4	yes	no
56	0	no	no	0	0	no	no	0	no	no	0	no	no
57	0	no	no	0	5	yes	no	0	no	no	6	yes	no
58	5	no	yes	5	5	no	yes	0	no	no	4	yes	no
59	2	yes	no	2	0	no	no	0	no	no	7	yes	no
60	2	yes	no	2	0	no	no	0	no	no	0	no	no
61	10	yes	no	10	0	no	no	0	no	no	1	yes	no
62	2	yes	no	2	0	no	no	1	yes	no	2	yes	no
63	0	no	no	0	0	no	no	0	no	no	3	yes	no

QID	Goat	GoatFarm	GoatGrass	Goat	Sheep	SheepHome	SheepGrass	Pig	PigHome	PigGrass	Chicken	ChickenFarm	ChickenGrass
64	6	yes	no	6	0	no	no	0	no	no	1	yes	no
65	6	yes	no	6	0	no	no	0	no	no	4	yes	no
66	10	no	yes	10	0	no	no	0	no	no	20	yes	no
67	0	no	no	0	0	no	no	2	yes	no	5	yes	no
68	5	yes	no	5	0	no	no	0	no	no	0	no	no
69	0	no	no	0	0	no	no	0	no	no	2	yes	no
70	10	yes	no	10	0	no	no	0	no	no	0	no	no
71	7	no	no	7	3	no	yes	0	no	no	0	no	no
72	50	yes	no	50	0	no	no	0	no	no	5	yes	no
73	40	yes	no	40	15	yes	no	0	no	no	0	no	no
74	2	no	yes	2	1	yes	no	0	no	no	1	yes	no
75	2	yes	no	2	0	no	no	0	no	no	3	yes	no
76	0	no	no	0	0	no	no	3	yes	no	1	yes	no
77	0	no	no	0	0	no	no	0	no	no	0	no	no
78	2	yes	no	2	0	no	no	0	no	no	0	no	no
79	5	yes	no	5	0	no	no	0	no	no	8	yes	no
80	5	yes	no	5	5	yes	no	3	yes	no	10	yes	no
81	5	yes	no	5	0	no	no	0	no	no	4	yes	no
82	3	yes	no	3	0	no	no	0	no	no	0	no	no
83	0	no	no	0	0	no	no	0	no	no	0	no	no
84	3	yes	no	3	0	no	no	1	yes	no	6	yes	no
85	4	yes	no	4	0	no	no	0	no	no	3	yes	no
86	4	yes	no	4	0	no	no	2	yes	no	4	yes	no
87	0	no	no	0	0	no	no	0	no	no	1	yes	no
88	1	yes	no	1	0	no	no	0	no	no	0	no	no
89	3	yes	no	3	0	no	no	0	no	no	2	yes	no
90	0	no	no	0	0	no	no	0	no	no	5	yes	no
91	0	no	no	0	0	no	no	0	no	no	0	no	no
92	0	no	no	0	0	no	no	0	no	no	2	yes	no
93	15	yes	no	15	0	no	no	4	yes	no	15	yes	no
94	5	yes	no	5	0	no	no	0	no	no	3	yes	no
95	0	no	no	0	0	no	no	0	no	no	0	no	no

QID	Goat	GoatFarm	GoatGrass	Goat	Sheep	SheepHome	SheepGrass	Pig	PigHome	PigGrass	Chicken	ChickenFarm	ChickenGrass
96	1	yes	no	1	0	no	no	0	no	no	2	yes	no
97	0	no	no	0	0	no	no	0	no	no	4	yes	no
98	0	no	no	0	0	no	no	0	no	no	3	yes	no
99	1	yes	no	1	0	no	no	0	no	no	5	yes	no
100	0	no	no	0	0	no	no	1	yes	no	7	yes	no
101	0	no	no	0	0	no	no	1	yes	no	1	no	no
102	0	no	no	0	0	no	no	0	no	no	6	yes	no
103	0	no	no	0	0	no	no	0	no	no	0	no	no
104	3	yes	no	3	0	no	no	0	no	no	3	yes	no
105	0	no	no	0	0	no	no	3	yes	no	1	yes	no
106	0	no	no	0	0	no	no	0	no	no	4	yes	no
107	7	yes	no	7	0	no	no	0	no	no	4	yes	no
108	6	yes	no	6	0	no	no	1	yes	no	5	yes	no
109	10	yes	no	10	0	no	no	2	yes	no	7	yes	no
110	0	no	no	0	0	no	no	0	no	no	2	yes	no
111	1	yes	no	1	0	no	no	3	yes	no	3	yes	no
112	3	yes	no	3	0	no	no	1	yes	no	7	yes	no
113	5	yes	no	5	0	no	no	1	yes	no	7	yes	no
114	5	yes	no	5	0	no	no	2	yes	no	4	yes	no
115	7	yes	no	7	0	no	no	0	no	no	4	yes	no
116	10	yes	no	10	0	no	no	0	no	no	0	no	no
117	0	no	no	0	0	no	no	0	no	no	0	no	no
118	0	no	no	0	0	no	no	0	no	no	0	no	no
119	3	yes	no	3	0	no	no	0	no	no	0	no	no
120	6	no	yes	6	0	no	no	0	no	no	10	yes	no
121	0	no	no	0	0	no	no	0	no	no	2	yes	no
122	0	no	no	0	0	no	no	0	no	no	7	yes	no
123	8	yes	no	8	0	no	no	3	yes	no	4	yes	no
124	5	yes	no	5	0	no	no	0	no	no	14	yes	no
125	1	yes	no	1	0	no	no	1	yes	no	1	yes	no
126	1	yes	no	1	0	no	no	0	no	no	1	yes	no
127	0	no	no	0	0	no	no	1	yes	no	4	yes	no

QID	Goat	GoatFarm	GoatGrass	Goat	Sheep	SheepHome	SheepGrass	Pig	PigHome	PigGrass	Chicken	ChickenFarm	ChickenGrass
128	0	no	no	0	0	no	no	0	no	no	0	no	no
129	7	yes	no	7	0	no	no	0	no	no	2	yes	no
130	1	yes	no	1	0	no	no	7	yes	no	0	no	no
131	39	no	yes	39	0	no	no	0	no	no	30	yes	no
132	0	no	no	0	0	no	no	0	no	no	0	no	no
133	0	no	no	0	0	no	no	0	no	no	0	no	no
134	0	no	no	0	0	no	no	0	no	no	0	no	no
135	0	no	no	0	0	no	no	0	no	no	4	yes	no
136	2	yes	no	2	0	no	no	0	no	no	0	no	no
137	0	no	no	0	0	no	no	0	no	no	12	yes	no
138	2	yes	no	2	0	no	no	0	no	no	2	yes	no
139	13	yes	no	13	0	no	no	0	no	no	15	yes	no
140	3	no	yes	3	3	no	yes	0	no	no	3	no	yes
141	2	yes	no	2	0	no	no	0	no	no	5	yes	no
142	0	no	no	0	0	no	no	0	no	no	0	no	no
143	0	no	no	0	0	no	no	0	no	no	12	yes	no
144	0	no	no	0	0	no	no	0	no	no	0	no	no
145	0	no	no	0	0	no	no	0	no	no	0	no	no
146	0	no	no	0	0	no	no	0	no	no	0	no	no
147	4	yes	no	4	0	no	no	0	no	no	5	yes	no
148	0	no	no	0	0	no	no	1	yes	no	0	no	no
149	0	no	no	0	3	yes	no	0	no	no	15	yes	no
150	6	yes	no	6	0	no	no	0	no	no	0	no	no

Table A-7 cont.: Agricultural information.

ID	CRC	CRF	FW	KWC	LM	LU	CA	AB	HU	HF
1	*in situ* kib	no fodder	not available	fodder	not used	not used	pit kib	not available	toilet	toilet
2	*in situ* kib	no fodder	not available	pit kib	*in situ* pit kib	not used	not used	not available	toilet	toilet
3	*in situ* kib	no fodder	not available	pit kib	pit kib	not used	pit kib	not available	toilet	toilet
4	*in situ* kib	no fodder	not available	*in situ* kib	*in situ* kib	not used	gathered in one place	not available	toilet	toilet
5	*in situ* kib	no fodder	not available	*in situ* kib	*in situ* kib	not used	pit kib	not available	toilet	toilet

ID	CRC	CRF	FW	KWC	LM	LU	CA	AB	HU	HF
6	*in situ* kib	no fodder	not available	pit kib	not used	not used	pit kib	not available	toilet	toilet
7	*in situ* kib	no fodder	not available	*in situ* kib	*in situ* kib	not used	*in situ* kib	not available	toilet	toilet
8	*in situ* kib	no fodder	not available	*in situ* kib	*in situ* kib	not used	*in situ* kib	not available	toilet	toilet
9	*in situ* kib	no fodder	not available	pit kib	pit kib	not used	gathered in one place	not available	pit kib	toilet
10	*in situ* kib	no fodder	fodder	*in situ* ring kib	not used	not used	*in situ* ring kib	not available	toilet	toilet
11	*in situ* ring pit kib	no fodder	not available	pit kib	not used	not used	gathered at one place	not available	toilet	toilet
12	*in situ* kib	no fodder	not available	pit kib	pit kib	not used	pesticide	not available	toilet	toilet
13	pit ring kib	no fodder	not available	pit ring kib	not used	not used	pit ring kib	not available	pesticide	toilet
14	*in situ* kib	no fodder	not available	fodder	not available	not available	toilet	not available	toilet	toilet
15	*in situ* kib	no fodder	not available	*in situ* kib	pit ring kib	not used	gathered at one place	not available	toilet	toilet
16	*in situ* ring kib	no fodder	fodder	fodder	*in situ* ring kib	not used	not used	not available	toilet	toilet
17	*in situ* kib	no fodder	*in situ* kib	*in situ* kib	*in situ* pit ring kib	not used	gathered at one place	not available	toilet	toilet
18	burnt	no fodder	not available	pit kib	in situ kib	not used	gathered at one place	not available	*in situ* kib	toilet
19	burnt	no fodder	not available	*in situ* kib	not available	not available	*in situ* kib	not available	toilet	toilet
20	ring kib	no fodder	not available	ring kib	not available	not available	ring kib	not available	toilet	toilet
21	*in situ* kib	no fodder	not available	pit kib	pit kib	not used	toilet	*in situ* kib	toilet	toilet
22	pit ring kib	no fodder	pit ring kib	pit ring kib	not used	not used	not available	not available	toilet	toilet
23	*in situ* kib	no fodder	not available	pit kib	not available	not available	pit kib	not available	toilet	toilet
24	*in situ* kib	no fodder	not available	*in situ* kib	*in situ* kib	*in situ* kib	*in situ* kib	not available	*in situ* kib	toilet
25	fodder	fodder	not available	pit ring kib	pit ring kib	not used	ring kib	not available	toilet	toilet
26	*in situ* ring kib	no fodder	not available	ring kib	not available	not available	pit kib	not available	toilet	toilet
27	pit ring kib	no fodder	not available	*in situ* kib	*in situ* kib	not used	*in situ* kib	not available	*in situ* kib	toilet
28	ring kib	no fodder	not available	*in situ* kib	*in situ* kib	not used	toilet	not available	*in situ* kib	toilet
29	ring kib	no fodder	fodder	pit kib	ring kib	*in situ* pit ring kib	pit kib	*in situ* kib	*in situ* kib	toilet
30	*in situ* kib	no fodder	pit kib	*in situ* kib	*in situ* kib	not used	gathered in one place	not available	toilet	toilet
31	*in situ* ring kib	no fodder	not available	*in situ* kib	*in situ* pit ring kib	not used	toilet	not available	toilet	toilet
32	not used	no fodder	fodder	fodder	pit kib	not used	pesticide	not available	*in situ* kib	toilet
33	pit kib	no fodder	not available	*in situ* kib	not available	not available	pesticide	not available	toilet	toilet
34	*in situ* ring kib	no fodder	*in situ* kib	pit kib	*in situ* kib	not used	*in situ* kib	not available	toilet	toilet
35	pit kib	no fodder	not available	pit kib	pit kib	pit kib	pesticide	not available	toilet	toilet
36	pit kib	no fodder	not available	fodder	not available	not available	gathered in one place	not available	*in situ* kib	toilet
37	*in situ* kib	no fodder	not available	*in situ* kib	not available	not available	pit kib	not available	toilet	toilet

ID	CRC	CRF	FW	KWC	LM	LU	CA	AB	HU	HF
38	*in situ* kib	no fodder	not available	*in situ* kib	ring kib	not used	gathered in one place	not available	toilet	toilet
39	pit ring kib	no fodder	fodder	pit kib	*in situ* pit ring kib	not used	*in situ* kib	not available	toilet	toilet
40	*in situ* ring pit kib	no fodder	*in situ* kib	*in situ* kib	not used	not used	pit kib	not available	toilet	toilet
41	*in situ* kib	no fodder	*in situ* kib	not available	not available	not available	gathered in one place	not available	*in situ* kib	toilet
42	pit ring kib	no fodder	not available	pit ring kib	pit ring kib	not used	*in situ* ring kib	not available	toilet	toilet
43	*in situ* ring pit kib	no fodder	not available	*in situ* kib	not available	not available	pit kib	not available	toilet	toilet
44	*in situ* ring pit kib	no fodder	fodder	pit kib	*in situ* kib	not used	gathered in one place	not available	*in situ* kib	toilet
45	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
46	*in situ* kib	no fodder	not available	*in situ* ring pit kib	*in situ* pit ring kib	not used	not used	not available	toilet	toilet
47	*in situ* kib	no fodder	not available	*in situ* kib	*in situ* kib	not used	pit kib	not available	toilet	toilet
48	not used	no fodder	*in situ* ring pit kib	*in situ* ring pit kib	not used	not used	pesticide	not available	toilet	toilet
49	pit kib	no fodder	burnt	pit ring kib	not used	not used	pit kib	not available	toilet	toilet
50	*in situ* kib	no fodder	not available	pit kib	*in situ* kib	not used	gathered in one place	not available	toilet	toilet
51	*in situ* kib	no fodder	not available	*in situ* kib	not available	not available	gathered in one place	not available	*in situ* kib	toilet
52	not used	no fodder	not available	pit kib	pit kib	not used	*in situ* kib	not available	*in situ* kib	toilet
53	*in situ* kib	no fodder	not available	pit kib	not available	not available	*in situ* kib	not available	toilet	toilet
54	*in situ* kib	no fodder	not available	*in situ* kib	*in situ* kib	not used	pit kib	not available	toilet	toilet
55	*in situ* kib	no fodder	not available	ring kib	ring kib	ring kib	*in situ* kib	not available	*in situ* kib	toilet
56	*in situ* ring pit kib	no fodder	not available	*in situ* ring pit kib	not available	not available	pit kib	not available	toilet	toilet
57	*in situ* kib	no fodder	not available	*in situ* kib	*in situ* pit ring kib	not used	*in situ* kib	not available	toilet	toilet
58	*in situ* kib	no fodder	pit kib	*in situ* kib	*in situ* pit ring kib	not used	gathered in one place	not available	toilet	toilet
59	*in situ* kib	no fodder	not available	pit kib	not used	not used	*in situ* kib	not available	toilet	toilet
60	*in situ* kib	no fodder	not available	*in situ* ring pit kib	*in situ* kib	not used	gathered in one place	not available	toilet	toilet
61	*in situ* ring pit kib	no fodder	*in situ* kib	pit kib	not used	not used	gathered in one place	not available	toilet	toilet
62	pit kib	no fodder	not available	pit kib	pit ring kib	not used	gathered in one place	not available	toilet	toilet
63	pit kib	no fodder	*in situ* kib	pit kib	not available	not available	pit kib	not available	toilet	toilet
64	*in situ* kib	no fodder	not available	pit kib	not available	not available	gathered at one place	not available	toilet	toilet
65	*in situ* kib	no fodder	fodder	pit kib	pit ring kib	*in situ* kib	pit kib	not available	toilet	toilet
66	*in situ* kib	no fodder	pit kib	pit kib	pit ring kib	not used	*in situ* kib	not available	toilet	toilet
67	*in situ* kib	no fodder	not available	pit kib	not used	not used	gathered in one place	not available	toilet	toilet
68	pit kib	no fodder	not available	pit kib	pit kib	not used	pesticide	not available	pesticide	toilet
69	not used	no fodder	not available	not available	not available	not available	*in situ* kib	not available	*in situ* kib	toilet

ID	CRC	CRF	FW	KWC	LM	LU	CA	AB	HU	HF
70	*in situ* kib	no fodder	not available	fodder	*in situ* kib	not used	pesticide	not available	toilet	toilet
71	*in situ* kib	no fodder	not available	pit kib	not used	not used	*in situ* kib	not available	*in situ* kib	toilet
72	pit kib	no fodder	not available	pit kib	pit kib	not used	gathered in one place	not available	pit kib	toilet
73	pit kib	no fodder	not available	*in situ* kib	*in situ* pit ring kib	not used	pit kib	not available	in situ kib	toilet
74	*in situ* kib	no fodder	not available	pit kib	not used	not used	*in situ* kib	not available	toilet	toilet
75	pit kib	no fodder	not available	pit kib	pit kib	not used	pit kib	not available	pit kib	toilet
76	*in situ* kib	no fodder	not available	*in situ* kib	not used	not used	gathered in one place	not available	*in situ* kib	toilet
77	*in situ* kib	no fodder	not available	*in situ* kib	not available	not available	*in situ* kib	not available	*in situ* kib	toilet
78	in situ kib	no fodder	not available	*in situ* kib	*in situ* pit ring kib	not used	*in situ* kib	not available	toilet	toilet
79	*in situ* kib	no fodder	not available	*in situ* kib	not used	not used	pit kib	not available	toilet	toilet
80	*in situ* kib	no fodder	not available	pit kib	pit kib	not used	not used	not available	toilet	toilet
81	pit ring kib	no fodder	not available	*in situ* kib	pit kib	not used	gathered at one place	not available	*in situ* kib	toilet
82	*in situ* kib	no fodder	not available	fodder	not used	not used	gathered at one place	not available	pit kib	toilet
83	*in situ* kib	no fodder	not available	*in situ* kib	not available	not available	gathered in one place	not available	toilet	toilet
84	*in situ* kib	no fodder	not available	*in situ* ring kib	pit ring kib	not used	gathered at one place	not available	*in situ* kib	toilet
85	pit ring kib	no fodder	not available	*in situ* kib	pit ring kib	not used	gathered at one place	not available	toilet	toilet
86	*in situ* kib	no fodder	fodder	*in situ* pit kib	pit ring kib	not used	*in situ* kib	not available	toilet	toilet
87	*in situ* kib	no fodder	not available	*in situ* kib	not available	not available	*in situ* kib	not available	toilet	toilet
88	*in situ* kib	no fodder	not available	*in situ* kib	*in situ* kib	not used	pit kib	not available	toilet	toilet
89	pit ring kib	no fodder	not available	pit kib	pit ring kib	not used	gathered in one place	not available	*in situ* kib	toilet
90	*in situ* pit kib	no fodder	not available	*in situ* pit kib	not used	not used	*in situ* kib	not available	toilet	toilet
91	*in situ* kib	no fodder	not available	*in situ* kib	not available	not available	*in situ* kib	not available	*in situ* kib	toilet
92	burnt	no fodder	not available	in situ pit kib	not available	not available	gathered in one place	not available	toilet	toilet
93	*in situ* kib	no fodder	*in situ* kib	fodder	*in situ* pit ring kib	not used	*in situ* kib	not available	toilet	toilet
94	*in situ* kib	no fodder	not available	pit kib	*in situ* pit ring kib	not used	gathered in one place	not available	toilet	toilet
95	*in situ* kib	no fodder	not available	*in situ* kib	not available	not available	*in situ* kib	not available	toilet	toilet
96	in situ kib	no fodder	not available	*in situ* kib	not used	not used	pit kib	not available	*in situ* kib	toilet
97	in situ pit kib	no fodder	not available	*in situ* pit kib	not available	not available	gathered in one place	not available	toilet	toilet
98	*in situ* kib	no fodder	not available	*in situ* kib	not available	not available	gathered in one place	not available	toilet	toilet
99	*in situ* pit kib	no fodder	not available	pit kib	not used	not used	pit kib	not available	pit kib	toilet
100	*in situ* pit kib	no fodder	not available	*in situ* kib	*in situ* kib	not used	gathered in one place	not available	*in situ* kib	toilet
101	*in situ* kib	no fodder	in situ kib	fodder	not used	not used	toilet	not available	toilet	toilet

ID	CRC	CRF	FW	KWC	LM	LU	CA	AB	HU	HF
102	in situ kib	no fodder	not available	*in situ* pit kib	not used	not used	gathered in one place	not available	*in situ* kib	toilet
103	pit kib	no fodder	not available	pit kib	not available	not available	gathered in one place	not available	toilet	toilet
104	*in situ* kib	no fodder	not available	pit kib	*in situ* kib	not used	pit kib	not available	toilet	toilet
105	*in situ* kib	no fodder	not available	*in situ* kib	not used	not used	gathered in one place	not available	toilet	toilet
106	*in situ* kib	no fodder	not available	*in situ* kib	not available	not available	toilet	not available	toilet	toilet
107	*in situ* kib	no fodder	not available	*in situ* kib	*in situ* pit kib	not used	gathered in one place	not available	toilet	toilet
108	*in situ* pit kib	no fodder	not available	*in situ* kib	pit ring kib	pit ring kib	*in situ* kib	not available	toilet	toilet
109	*in situ* kib	no fodder	not available	*in situ* kib	pit ring kib	not used	gathered in one place	not available	toilet	toilet
110	*in situ* kib	no fodder	not available	pit kib	not available	not available	pit kib	not available	toilet	toilet
111	*in situ* kib	no fodder	not available	pit ring kib	not used	not used	gathered in one place	not available	toilet	toilet
112	*in situ* kib	no fodder	not available	pit kib	not used	not used	gathered in one place	not available	toilet	toilet
113	*in situ* kib	no fodder	*in situ* kib	not available	not used	not used	gathered in one place	not available	*in situ* kib	toilet
114	*in situ* kib	no fodder	not available	*in situ* kib	not used	not used	pit kib	not available	*in situ* kib	toilet
115	*in situ* kib	no fodder	not available	pit kib	*in situ* pit kib	not used	pit kib	not available	toilet	toilet
116	*in situ* kib	no fodder	pit kib	pit kib	pit ring kib	not used	pit kib	not available	pit kib	toilet
117	*in situ* kib	no fodder	not available	*in situ* kib	not used	not used	gathered in one place	not available	*in situ* kib	toilet
118	*in situ* kib	no fodder	not available	pit kib	not available	not available	pit kib	not available	toilet	toilet
119	*in situ* kib	no fodder	not available	*in situ* kib	not used	not used	pit kib	not available	*in situ* kib	toilet
120	*in situ* kib	no fodder	fodder	*in situ* kib	*in situ* pit kib	not used	toilet	not available	toilet	toilet
121	pit kib	no fodder	not available	*in situ* pit kib	not available	not available	gathered in one place	not available	*in situ* kib	toilet
122	*in situ* kib	no fodder	not available	*in situ* pit kib	not used	not used	gathered in one place	not available	pesticide	toilet
123	*in situ* kib	no fodder	*in situ* kib	*in situ* kib	*in situ* kib	not used	gathered in one place	pit kib	*in situ* kib	toilet
124	*in situ* kib	no fodder	fodder	fodder	*in situ* pit kib	not used	gathered in one place	not available	toilet	toilet
125	*in situ* kib	no fodder	not available	pit kib	not used	not used	gathered in one place	not available	*in situ* kib	toilet
126	*in situ* kib	no fodder	not available	*in situ* kib	*in situ* kib	not used	pit kib	not available	toilet	toilet
127	*in situ* kib	no fodder	not available	*in situ* kib	not used	not used	in situ kib	not available	*in situ* kib	toilet
128	pit kib	no fodder	not available	pit kib	not available	not available	gathered in one place	not available	pesticide	toilet
129	*in situ* kib	no fodder	not available	pit kib	*in situ* pit kib	not used	gathered in one place	not available	toilet	toilet
130	*in situ* kib	no fodder	not available	pit kib	*in situ* pit kib	not used	toilet	not available	toilet	toilet
131	*in situ* kib	no fodder	not available	*in situ* pit kib	*in situ* pit kib	not used	pesticide	not available	pesticide	toilet
132	*in situ* kib	no fodder	not available	*in situ* kib	not available	not available	gathered in one place	not available	*in situ* kib	toilet
133	*in situ* kib	no fodder	not available	pit kib	not available	not available	gathered in one place	not available	toilet	toilet

ID	CRC	CRF	FW	KWC	LM	LU	CA	AB	HU	HF
134	*in situ* pit kib	no fodder	not available	*in situ* kib	not used	not used	gathered in one place	not available	*in situ* kib	toilet
135	*in situ* kib	no fodder	not available	*in situ* kib	not available	not available	*in situ* kib	not available	toilet	toilet
136	pit ring kib	no fodder	not available	*in situ* pit kib	pit ring kib	not used	*in situ* kib	not available	*in situ* kib	toilet
137	*in situ* kib	no fodder	not available	in situ kib	in situ pit kib	not used	gathered in one place	not available	toilet	toilet
138	*in situ* kib	no fodder	*in situ* pit kib	pit ring kib	not used	not used	gathered in one place	not available	toilet	toilet
139	*in situ* kib	no fodder	not available	in situ kib	pit ring kib	not used	gathered in one place	not available	toilet	toilet
140	*in situ* kib	no fodder	fodder	pit kib	pit ring kib	not used	gathered in one place	not available	toilet	toilet
141	*in situ* kib	no fodder	not available	*in situ* pit kib	in situ pit ring kib	not used	gathered in one place	not available	toilet	toilet
142	pit kib	no fodder	not available	pit kib	not available	not available	pit kib	not available	*in situ* kib	toilet
143	*in situ* kib	no fodder	not available	ring kib	not used	not used	pesticide	not available	toilet	toilet
144	*in situ* kib	no fodder	not available	in situ pit kib	not available	not available	toilet	not available	toilet	toilet
145	*in situ* kib	no fodder	not available	pit ring kib	*in situ* kib	not used	gathered in one place	not available	*in situ* kib	toilet
146	*in situ* kib	no fodder	not available	*in situ* pit kib	not available	not available	gathered in one place	not available	toilet	toilet
147	*in situ* kib	no fodder	not available	pit kib	not used	not used	gathered in one place	not available	*in situ* kib	toilet
148	*in situ* kib	no fodder	*in situ* kib	*in situ* pit kib	not used	not used	gathered in one place	not available	toilet	toilet
149	*in situ* kib	no fodder	not available	*in situ* pit kib	pit ring kib	not used	gathered in one place	not available	toilet	toilet
150	*in situ* kib	no fodder	not available	pit kib	*in situ* kib	not used	*in situ* kib	not available	pesticide	toilet

8.2.8 Economic data and Water-Energy-Food (WEF) Nexus

Table A 8: Legend of economic data and data regarding the WEF Nexus.

Variable	Unit	Name	Description
MarketDis	km	Distance to the market	Distance to the nearest local market.
MarketTime	hours	Time needed to the market	Time needed to the nearest local market.
MarketTransp	walking / bicycle / motor-cycle / car	Market transportation	Transportation means to get goods to or from the market.
LabHire	yes/no	Hired labour	The household hires labour.
WorkOff	yes, in agricultural jobs / yes in non-agricultural jobs /no	Working off-farm	At least one adult household member works off-farm.
Housing	mud house / brick house	Type of house	Type of the main farmhouse.
Transport	none / bicycle / motorcycle / car	Transport means / vehicles	Available transport means / vehicles.
Toilet	normal pit latrine / im-proved pit latrine / flush toilet	Type of toilet	Type of toilet. Normal pit latrines have a mud floor and a temporary roof, wall, and door. Improved pit latrines have a wooden or brick floor and a solid roof, walls, and door.
Stream	yes/no	Stream water	Stream water used as drinking water.
Well	yes/no	Well	Water from the well-used as drinking water.
Rain	yes/no	Rainwater	Rainwater used as drinking water.
Filt	yes/no	Filtering drinking water	The collected water is filtered.
Boil	yes/no	Boiling drinking water	The collected water is boiled.
ChemTreat	yes/no	Chemical treatment of drinking water	The collected water is chemically treated.
OtherTreat	yes/no	No treatment of drinking water	The collected water is not treated.
FuelCooking	gathered wood / grass / cut wood / purchased charcoal / produced charcoal / fossil fuels	Cooking fuel	Fuel used for cooking. Grass is often used to start the fire
Food secure	months/year	Annual food security per household	Total number of months in which the household had enough food to eat within one year from September 2016 to August 2017, 12 months.

Table A 9: Economic data and data regarding the WEF Nexus.

QID	MarketDis	MarketTime	MarketTransp	LabHire	WorkOff	Housing	Transport	FuelCooking	Toilet
1	5	60	Walking, motorcycle	yes	yes, in non-agricultural jobs	brick house	motorcycle	cut wood, gathered wood, purchased charcoal	improved pit latrine
2	6	n.a.	Motorcycle	yes	no	brick house	none	cut wood	improved pit latrine
3	6	60	Walking	no	yes, in non-agricultural jobs	mud house	none	cut wood, purchased charcoal, grass, produced charcoal	normal pit latrine
4	6	120	Walking	yes	no	brick house	motorcycle	cut wood, gathered wood, purchased charcoal	improved pit latrine
5	2.5	90	Walking	no	no	mud house	none	cut wood, produced charcoal	normal pit latrine
6	4	n.a.	Motorcycle	yes	yes, in non-agricultural jobs	mud house	motorcycle	cut wood, gathered wood	normal pit latrine
7	n.a.	n.a.	Walking	no	no	mud house	none	gathered wood	normal pit latrine
8	2	60	Walking	no	yes, in non-agricultural jobs	brick house	none	cut wood, produced charcoal	normal pit latrine
9	6	90	Walking, motorcycle	yes	yes, in agricultural jobs	brick house	car	cut wood, gathered wood, produced charcoal	improved pit latrine
10	1.5	n.a.	Walking	yes	yes, in non-agricultural jobs	brick house	car	cut wood, gathered wood, grass	normal pit latrine
11	10	60	Motorcycle	yes	no	brick house	motorcycle	cut wood	normal pit latrine
12	10	120	Walking	no	no	mud house	none	cut wood, produced charcoal	normal pit latrine
13	8	90	Walking	no	no	mud house	none	gathered wood	normal pit latrine
14	1	10	Walking	no	no	brick house	none	gathered wood, purchased charcoal, grass	normal pit latrine
15	1	15	Walking	no	yes, in agricultural jobs	brick house	none	cut wood, gathered wood	normal pit latrine
16	1	30	Walking	yes	yes, in non-agricultural jobs	brick house	bicycle	cut wood, gathered wood, purchased charcoal	improved pit latrine
17	3	60	Walking	no	no	mud house	none	cut wood, purchased charcoal	normal pit latrine
18	10	120	Walking	no	no	brick house	motorcycle	gathered wood, purchased charcoal	normal pit latrine

QID	MarketDis	MarketTime	MarketTransp	LabHire	WorkOff	Housing	Transport	FuelCooking	Toilet
19	0.5	30	Walking	no	no	mud house	none	cut wood, gathered wood	normal pit latrine
20	8	n.a.	Car	yes	yes, in non-agricultural jobs	brick house	car	gathered wood, purchased charcoal, produced charcoal, fossil fuels	improved pit latrine
21	2	30	Walking	yes	yes, in non-agricultural jobs	brick house	motorcycle	cut wood, produced charcoal	normal pit latrine
22	2	120	Walking	yes	no	brick house	none	cut wood	improved pit latrine
23	1.5	60	Walking	no	yes, in agricultural jobs	mud house	none	cut wood, gathered wood, grass	normal pit latrine
24	4	60	Walking	no	no	brick house	none	gathered wood	normal pit latrine
25	2	30	Walking	yes	no	brick house	car	cut wood, gathered wood, produced charcoal	normal pit latrine
26	1	20	Walking	no	yes, in agricultural jobs	mud house	none	gathered wood, produced charcoal	normal pit latrine
27	2	90	Walking, motorcycle, bicycle	no	no	brick house	motorcycle	gathered wood, sol, fossil fuels	normal pit latrine
28	12	120	Walking	no	no	mud house	none	gathered wood, grass	normal pit latrine
29	4	15	Walking, motorcycle	yes	yes, in non-agricultural jobs	brick house	motorcycle	cut wood, gathered wood, purchased charcoal, fossil fuels	normal pit latrine
30	1.5	30	Walking	yes	yes, in non-agricultural jobs	brick house	none	cut wood, gathered wood, purchased charcoal, grass	improved pit latrine
31	3	120	Walking	yes	yes, in non-agricultural jobs	mud house	none	cut wood, gathered wood	normal pit latrine
32	2.5	60	Walking	yes	no	brick house	motorcycle	cut wood, gathered wood	improved pit latrine
33	0.5	90	Walking	no	no	mud house	none	gathered wood	normal pit latrine
34	8	20	Car	yes	yes, in non-agricultural jobs	brick house	car	cut wood, gathered wood, purchased charcoal, fossil fuels	flush toilet
35	10	120	Walking	no	no	mud house	bicycle	gathered wood	normal pit latrine
36	2	30	Walking	no	no	brick house	car	gathered wood, sol	improved pit latrine
37	9	60	Walking, motorcycle	yes	yes, in non-agricultural jobs	brick house	none	cut wood, purchased charcoal, grass	normal pit latrine
38	2	30	Walking	no	no	mud house	bicycle	gathered wood, grass	normal pit latrine

QID	MarketDis	MarketTime	MarketTransp	LabHire	WorkOff	Housing	Transport	FuelCooking	Toilet
39	8	20	Walking	yes	no	brick house	motorcycle	gathered wood	normal pit latrine
40	0.5	10	Walking	yes	yes, in non-agricultural jobs	brick house	motorcycle	purchased charcoal, fossil fuels	flush toilet
41	1.5	10	Walking	yes	no	mud house	bicycle	gathered wood, grass	normal pit latrine
42	2	60	Walking	no	no	mud house	none	gathered wood	normal pit latrine
43	2	60	Walking	no	yes, both.	brick house	none	gathered wood	normal pit latrine
44	1	60	Walking	yes	no	mud house	none	cut wood, gathered wood, grass, fossil fuels	normal pit latrine
45	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
46	5	120	Walking	yes	no	brick house	none	gathered wood	normal pit latrine
47	10	240	Walking	no	yes, in agricultural jobs	mud house	none	gathered wood	normal pit latrine
48	7	120	Walking	no	yes, in non-agricultural jobs	mud house	none	cut wood	normal pit latrine
49	7	90	Walking, car	yes	no	brick house	motorcycle	cut wood, gathered wood, purchased charcoal	normal pit latrine
50	10	120	Walking	no	no	brick house	none	cut wood, gathered wood, purchased charcoal	normal pit latrine
51	7	180	Walking	yes	no	brick house	none	cut wood, gathered wood	normal pit latrine
52	6	180	Walking	no	no	brick house	none	gathered wood	normal pit latrine
53	5	60	Walking	yes	yes, in non-agricultural jobs	brick house	bicycle	cut wood, gathered wood	flush toilet
54	5	120	Walking	no	no	brick house	none	cut wood	normal pit latrine
55	4	60	Walking	yes	yes, in non-agricultural jobs	brick house	none	cut wood	normal pit latrine
56	10	60	Walking	no	yes, in non-agricultural jobs	brick house	motorcycle	cut wood, gathered wood, grass	normal pit latrine
57	4	90	Walking	yes	no	brick house	bicycle	cut wood	normal pit latrine
58	4.5	60	Walking	no	no	brick house	motorcycle	cut wood, gathered wood, grass	normal pit latrine
59	10	60	Walking	no	yes, in non-agricultural jobs	mud house	none	cut wood, gathered wood	normal pit latrine
60	10	120	Walking	no	yes, in non-agricultural jobs	brick house	none	gathered wood	normal pit latrine

QID	MarketDis	MarketTime	MarketTransp	LabHire	WorkOff	Housing	Transport	FuelCooking	Toilet
61	0.5	10	Walking	yes	yes, in non-agricultural jobs	mud house	motorcycle	cut wood, gathered wood, purchased charcoal, grass	improved pit latrine
62	1	40	Walking	no	no	brick house	none	gathered wood, purchased charcoal, grass	improved pit latrine
63	0.1	5	Walking	yes	no	brick house	none	cut wood	normal pit latrine
64	0.25	10	Walking	no	yes, in non-agricultural jobs	mud house	none	cut wood, gathered wood, purchased charcoal	normal pit latrine
65	1	15	Motorcycle	yes	yes, in non-agricultural jobs	brick house	motorcycle	gathered wood, grass	normal pit latrine
66	1	15	Walking	yes	no	brick house	car	cut wood, gathered wood	improved pit latrine
67	0.5	20	Walking	yes	yes, in non-agricultural jobs	brick house	motorcycle	cut wood, gathered wood	improved pit latrine
68	3	45	Walking	no	no	brick house	bicycle	cut wood	normal pit latrine
69	0.1	30	Walking	no	no	mud house	none	gathered wood	normal pit latrine
70	1	60	Walking	yes	yes, in non-agricultural jobs	mud house	none	cut wood, gathered wood, purchased charcoal	normal pit latrine
71	3	60	Walking	yes	yes, in agricultural jobs	brick house	bicycle	cut wood, gathered wood, sol	improved pit latrine
72	4	90	Walking	no	yes, in non-agricultural jobs	brick house	motorcycle	cut wood	normal pit latrine
73	1	40	Walking	yes	no	brick house	motorcycle	cut wood	improved pit latrine
74	0.5	20	Walking	yes	yes, in non-agricultural jobs	mud house	none	gathered and cut wood	normal pit latrine
75	0.25	30	Walking	no	no	mud house	none	gathered wood, grass	normal pit latrine
76	2.1	60	Walking	no	yes, in non-agricultural jobs	mud house	none	gathered wood	normal pit latrine
77	3.5	120	Walking	no	no	mud house	none	gathered wood	normal pit latrine
78	5	30	Walking	yes	yes, in non-agricultural jobs	mud house	none	cut wood, gathered wood, purchased charcoal	normal pit latrine
79	4	60	Walking	yes	no	brick house	none	cut wood, gathered wood	normal pit latrine
80	1	60	Walking	yes	yes, in non-agricultural jobs	brick house	motorcycle	cut wood, gathered wood, grass	improved pit latrine
81	7	120	Walking	yes	no	brick house	none	gathered wood	normal pit latrine
82	5	120	Walking	no	no	brick house	none	cut wood, gathered wood	normal pit latrine

QID	MarketDis	MarketTime	MarketTransp	LabHire	WorkOff	Housing	Transport	FuelCooking	Toilet
83	3	60	Walking	no	no	mud house	none	cut wood, gathered wood	normal pit latrine
84	7	120	Walking	yes	no	mud house	none	gathered wood, grass, fossil fuels	normal pit latrine
85	3	60	Walking	no	yes, in non-agricultural jobs	mud house	none	gathered wood, grass, fossil fuels	normal pit latrine
86	6	5	Motorcycle	yes	yes, in non-agricultural jobs	brick house	motorcycle	cut wood, gathered wood, grass	normal pit latrine
87	5	300	Walking	no	no	mud house	none	gathered wood	normal pit latrine
88	5	10	Car	no	no	mud house	none	cut wood, gathered wood, purchased charcoal, grass	normal pit latrine
89	4	45	Walking, motorcycle	no	no	brick house	none	gathered wood	normal pit latrine
90	4.2	120	Car	no	no	mud house	none	gathered wood, grass	normal pit latrine
91	3	120	Walking	no	yes, in agricultural jobs	mud house	none	gathered wood	normal pit latrine
92	3	90	Walking	no	no	mud house	none	gathered wood	normal pit latrine
93	3	40	Walking	yes	yes, in non-agricultural jobs	brick house	motorcycle	cut wood, gathered wood	normal pit latrine
94	2.5	60	Walking	yes	yes, in non-agricultural jobs	brick house	none	cut wood, gathered wood, grass	normal pit latrine
95	5	40	Walking	no	yes, in non-agricultural jobs	mud house	none	gathered wood	normal pit latrine
96	2.1	60	Walking	no	no	brick house	none	gathered wood, grass	normal pit latrine
97	2	30	Walking	no	no	brick house	bicycle	cut wood, gathered wood	normal pit latrine
98	7	90	Walking	no	no	mud house	none	gathered wood	normal pit latrine
99	4	120	Walking	no	no	mud house	none	gathered wood	normal pit latrine
100	5	60	Walking	no	no	brick house	none	gathered and cut wood	normal pit latrine
101	7	120	Walking	yes	yes, in non-agricultural jobs	mud house	none	cut wood, gathered wood	normal pit latrine
102	5	60	n.a.	no	No	mud house	bicycle	gathered wood	normal pit latrine
103	4	90	Walking	no	no	mud house	bicycle	gathered wood	normal pit latrine
104	9	180	Walking	no	yes, in non-agricultural jobs	mud house	none	cut wood, gathered wood	normal pit latrine
105	3.1	90	Walking	no	no	brick house	none	gathered wood	normal pit latrine

QID	MarketDis	MarketTime	MarketTransp	LabHire	WorkOff	Housing	Transport	FuelCooking	Toilet
106	1	30	Walking	no	no	brick house	none	fossil fuels	improved pit latrine
107	7	180	Walking	yes	no	mud house	none	cut wood, gathered wood, grass	normal pit latrine
108	2	30	Walking	no	no	mud house	none	gathered wood, grass	normal pit latrine
109	1	25	Walking	yes	no	brick house	motorcycle	cut wood, gathered wood	improved pit latrine
110	1	10	Walking	yes	yes, in non-agricultural jobs	brick house	bicycle	gathered and cut wood	normal pit latrine
111	3	50	Walking	no	yes, in agricultural jobs	mud house	none	gathered wood	normal pit latrine
112	1	15	Walking	yes	yes, in non-agricultural jobs	brick house	none	cut wood, gathered wood	normal pit latrine
113	1	30	Walking	yes	no	mud house	bicycle	gathered wood, grass	normal pit latrine
114	0.5	20	Walking	yes	yes, in non-agricultural jobs	brick house	bicycle	gathered wood	pour toilet with septic tank
115	2	15	Walking	yes	yes, in non-agricultural jobs	brick house	motorcycle	cut wood, gathered wood	improved pit latrine
116	1	30	Walking	no	no	mud house	none	cut wood	normal pit latrine
117	0.5	20	Walking	yes	yes, in non-agricultural jobs	brick house	bicycle	gathered wood	normal pit latrine
118	2	15	Walking	yes	yes, in non-agricultural jobs	brick house	none	cut wood, gathered wood	normal pit latrine
119	1	5	Walking	yes	yes, in non-agricultural jobs	mud house	none	cut wood, gathered wood	normal pit latrine
120	4	5	Motorcycle	yes	yes, in non-agricultural jobs	brick house	motorcycle	gathered wood	improved pit latrine
121	3	60	Walking	no	no	mud house	none	cut wood, gathered wood, grass	normal pit latrine
122	3	30	Walking	yes	no	brick house	none	cut wood	normal pit latrine
123	4	80	Walking	no	yes, in non-agricultural jobs	brick house	none	gathered wood, grass	normal pit latrine
124	4	35	Walking	yes	yes, in non-agricultural jobs	brick house	motorcycle	cut wood, gathered wood, grass	normal pit latrine
125	5	50	Walking	no	no	mud house	bicycle	gathered wood	normal pit latrine
126	3	30	Walking	yes	yes, in non-agricultural jobs	mud house	motorcycle	cut wood, gathered wood	normal pit latrine

QID	MarketDis	MarketTime	MarketTransp	LabHire	WorkOff	Housing	Transport	FuelCooking	Toilet
127	15	60	Walking	no	no	mud house	motorcycle	gathered wood, grass	normal pit latrine
128	0.5	20	Walking	no	no	mud house	none	cut wood	normal pit latrine
129	1	60	Walking	yes	no	brick house	none	gathered wood	normal pit latrine
130	2	60	Walking	yes	no	brick house	none	cut wood, gathered wood	normal pit latrine
131	2	30	Walking	yes	no	brick house	motorcycle	cut wood, gathered wood	normal pit latrine
132	1	40	Walking	no	no	brick house	none	cut wood, grass	normal pit latrine
133	2	30	Walking	yes	no	brick house	motorcycle	cut wood, gathered wood	normal pit latrine
134	3	30	Walking	no	no	mud house	none	gathered wood	normal pit latrine
135	1	15	Walking	yes	no	brick house	none	cut wood, gathered wood, grass	normal pit latrine
136	1	60	Walking	no	no	brick house	none	cut wood	normal pit latrine
137	0.5	3	Walking	yes	no	brick house	motorcycle	cut wood, gathered wood, purchased charcoal	improved pit latrine
138	0.8	10	Walking	yes	no	brick house	motorcycle	cut wood, gathered wood	normal pit latrine
139	1	15	Walking	yes	yes, in non-agricultural jobs	mud house	bicycle	cut wood, gathered wood, purchased charcoal	normal pit latrine
140	0.5	15	Walking	no	no	brick house	motorcycle	cut wood, gathered wood	pour toilet with septic tank
141	2	1	Walking	yes	yes, in non-agricultural jobs	brick house	none	cut wood, gathered wood	normal pit latrine
142	1	30	Walking	no	no	mud house	none	cut wood	normal pit latrine
143	5	60	Walking	yes	no	brick house	motorcycle	cut wood, gathered wood, purchased charcoal	normal pit latrine
144	2	120	Walking	no	yes, in non-agricultural jobs	mud house	none	gathered wood	normal pit latrine
145	0.7	20	Walking	yes	no	mud house	none	cut wood, gathered wood, grass	normal pit latrine
146	0.1	5	Walking	no	no	brick house	bicycle	cut wood, gathered wood, purchased charcoal	improved pit latrine
147	0	1	Walking	yes	no	mud house	none	gathered wood, grass, fossil fuels	normal pit latrine
148	3	90	Walking	yes	yes, in non-agricultural jobs	mud house	none	cut wood, gathered wood	normal pit latrine
149	1	45	Walking	yes	yes, in non-agricultural jobs	mud house	none	cut wood, gathered wood, grass	normal pit latrine

Table A-9 cont.: Economic data and data regarding the Water-Energy-Food (WEF) Nexus.

QID	Stream	Well	Rain	Filt	Boil	ChemTreat	OtherTreat	Food secure
1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	7
2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	12
3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0
4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	8
5	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0
6	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	4
7	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0
8	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	10
9	Yes	No	No	No	Yes	No	No	10
10	Yes	No	Yes	No	Yes	No	No	0
11	Yes	No	Yes	Yes	Yes	No	No	0
12	Yes	No	No	No	No	No	No	0
13	Yes	No	Yes	Yes	Yes	No	No	9
14	Yes	No	No	Yes	No	No	No	0
15	No	Yes	Yes	No	No	No	No	0
16	Yes	No	Yes	Yes	Yes	No	No	12
17	Yes	No	Yes	No	No	No	No	0
18	Yes	No	No	No	No	No	No	4
19	Yes	No	Yes	Yes	Yes	No	No	0
20	Yes	No	Yes	No	Yes	No	No	9
21	Yes	Yes	No	Yes	Yes	No	No	8
22	No	Yes	Yes	No	Yes	No	No	0
23	No	No	Yes	Yes	Yes	No	No	0
24	Yes	No	No	No	Yes	No	No	0
25	Yes	No	Yes	No	Yes	No	No	0
26	Yes	No	No	No	No	No	No	0
27	No	Yes	No	No	Yes	No	No	0
28	No	Yes	No	No	No	No	No	0
29	Yes	No	No	No	Yes	No	No	10
30	Yes	No	Yes	No	Yes	No	No	0
31	Yes	Yes	Yes	Yes	No	No	No	8

QID	Stream	Well	Rain	Filt	Boil	ChemTreat	OtherTreat	Food secure
32	Yes	No	No	Yes	Yes	No	No	0
33	No	Yes	Yes	No	No	No	No	0
34	No	Yes	Yes	No	Yes	No	No	7
35	No	Yes	Yes	No	No	No	No	0
36	Yes	No	No	Yes	Yes	No	No	0
37	Yes	Yes	Yes	No	Yes	No	No	4
38	Yes	No	No	No	Yes	No	No	2
39	Yes	No	Yes	No	No	No	No	0
40	Yes	No	Yes	Yes	Yes	No	No	9
41	No	Yes	No	No	No	No	No	0
42	Yes	Yes	Yes	No	Yes	No	No	0
43	No	Yes	Yes	No	Yes	No	No	0
44	Yes	No	No	No	No	No	No	0
45	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	12
46	Yes	No	Yes	Yes	Yes	No	No	0
47	Yes	No	Yes	No	No	No	No	0
48	Yes	No	Yes	Yes	Yes	No	No	0
49	Yes	No	No	No	Yes	No	No	0
50	Yes	No	Yes	Yes	Yes	No	No	0
51	Yes	No	Yes	Yes	Yes	No	No	8
52	Yes	No	No	No	No	No	No	0
53	Yes	No	Yes	Yes	No	No	No	10
54	Yes	No	Yes	No	Yes	No	No	0
55	Yes	No	No	No	No	No	No	6
56	Yes	No	Yes	No	Yes	No	No	0
57	Yes	No	Yes	No	Yes	No	No	10
58	Yes	No	No	No	No	No	No	8
59	Yes	No	Yes	No	Yes	No	No	0
60	Yes	No	No	Yes	Yes	No	No	7
61	No	No	Yes	No	Yes	No	No	12
62	No	Yes	Yes	Yes	Yes	No	No	3
63	Yes	No	Yes	No	Yes	No	No	4

QID	Stream	Well	Rain	Filt	Boil	ChemTreat	OtherTreat	Food secure
64	Yes	Yes	Yes	No	Yes	Yes	No	3
65	No	Yes	No	No	No	No	No	8
66	Yes	No	Yes	Yes	Yes	No	No	0
67	Yes	No	Yes	No	Yes	No	No	4
68	Yes	No	Yes	Yes	Yes	No	No	0
69	Yes	No	No	No	No	No	No	0
70	Yes	No	Yes	No	Yes	No	No	1
71	Yes	No	No	Yes	Yes	No	No	8
72	Yes	No	Yes	No	Yes	No	No	6
73	Yes	No	Yes	No	No	No	No	9
74	Yes	No	Yes	No	Yes	No	No	0
75	Yes	No	No	Yes	Yes	No	No	5
76	Yes	No	Yes	No	Yes	No	No	6
77	No	Yes	No	Yes	Yes	No	No	0
78	Yes	No	Yes	No	Yes	No	No	0
79	No	Yes	Yes	No	Yes	No	No	0
80	Yes	No	Yes	No	Yes	No	No	4
81	Yes	No	No	No	Yes	No	No	2
82	Yes	Yes	Yes	No	No	No	No	4
83	Yes	No	Yes	No	Yes	No	No	0
84	Yes	No	No	No	No	No	No	0
85	Yes	No	Yes	No	No	No	No	0
86	Yes	No	Yes	No	Yes	No	No	7
87	Yes	No	Yes	No	No	No	No	0
88	Yes	No	Yes	No	Yes	No	No	0
89	Yes	No	No	No	Yes	No	No	7
90	Yes	No	No	No	No	No	No	11
91	Yes	No	No	Yes	Yes	No	No	0
92	No	Yes	Yes	No	No	No	No	0
93	Yes	No	Yes	No	Yes	No	No	9
94	Yes	No	Yes	No	No	No	No	9
95	No	Yes	Yes	No	Yes	No	No	0

QID	Stream	Well	Rain	Filt	Boil	ChemTreat	OtherTreat	Food secure
96	No	Yes	No	No	No	No	No	0
97	Yes	Yes	Yes	No	Yes	No	No	0
98	Yes	No	Yes	No	No	No	No	0
99	Yes	No	No	No	Yes	No	No	0
100	Yes	Yes	Yes	No	Yes	No	No	0
101	Yes	No	Yes	No	No	No	No	0
102	Yes	Yes	Yes	Yes	No	No	No	0
103	No	Yes	No	Yes	Yes	No	No	8
104	Yes	No	Yes	No	No	No	No	0
105	No	Yes	No	No	No	No	No	0
106	No	Yes	Yes	Yes	Yes	No	No	12
107	Yes	No	Yes	No	No	No	No	9
108	No	Yes	No	No	Yes	No	No	2
109	No	No	Yes	Yes	Yes	No	No	12
110	No	No	Yes	No	Yes	No	No	12
111	No	Yes	Yes	Yes	Yes	No	No	9
112	Yes	No	Yes	No	Yes	No	No	1
113	No	Yes	Yes	No	Yes	No	No	0
114	No	No	Yes	No	Yes	No	No	12
115	Yes	No	Yes	No	Yes	No	No	10
116	Yes	No	No	No	Yes	No	No	9
117	No	No	Yes	No	No	Yes	No	11
118	Yes	No	Yes	No	No	No	No	10
119	No	Yes	Yes	No	Yes	No	No	12
120	Yes	No	Yes	No	Yes	No	No	0
121	No	Yes	No	No	No	No	No	10
122	Yes	No	Yes	Yes	No	No	No	8
123	No	Yes	Yes	No	Yes	No	No	9
124	Yes	No	Yes	No	Yes	No	No	10
125	No	No	Yes	No	No	No	No	12
126	Yes	No	Yes	Yes	Yes	No	No	0
127	Yes	No	No	No	No	No	No	4

QID	Stream	Well	Rain	Filt	Boil	ChemTreat	OtherTreat	Food secure
128	Yes	No	Yes	No	No	No	No	0
129	Yes	No	No	Yes	Yes	No	No	10
130	Yes	No	Yes	No	Yes	No	No	10
131	Yes	No	Yes	Yes	No	No	No	9
132	No	No	Yes	No	Yes	No	No	9
133	Yes	No	Yes	No	No	No	No	0
134	No	Yes	No	No	Yes	No	No	0
135	Yes	No	Yes	No	Yes	No	No	4
136	No	Yes	No	No	Yes	No	No	11
137	No	Yes	Yes	Yes	No	No	No	8
138	Yes	No	No	No	No	No	No	0
139	Yes	No	Yes	No	Yes	No	No	10
140	No	Yes	Yes	Yes	No	No	No	0
141	Yes	No	Yes	No	Yes	No	No	8
142	Yes	No	No	No	Yes	No	No	10
143	No	Yes	Yes	No	Yes	No	No	11
144	Yes	No	No	No	No	No	No	0
145	No	Yes	No	No	No	No	No	0
146	No	Yes	No	No	No	No	No	0
147	No	No	Yes	No	Yes	No	No	10
148	Yes	No	Yes	No	Yes	No	No	0
149	Yes	No	Yes	No	No	No	No	6
150	Yes	No	Yes	No	No	No	No	9

8.2.10 Gender-specific distribution of tasks within the farming family

Table A 10: Legend of gender-specific distribution of tasks.

Variable	Unit	Name	Description
SeedsOwn	female / male / both	Responsibility of the tasks "producing own seeds"	Responsibility of the tasks "producing own seeds"
SeedsExch	female / male / both	Responsibility of the tasks "exchanging seeds"	Responsibility of the tasks "exchanging seeds"
WeedCon/Till	female / male / both	Responsibility of the tasks "weed control by tillage"	Responsibility of the tasks "weed control by tillage"
Terr	female / male / both	Responsibility of the tasks "terracing"	Responsibility of the tasks "terracing"
OMField	female / male / both	Responsibility of the tasks "distributing organic material to the field"	Responsibility of the tasks "distributing organic material to the field"
AnuCrop	female / male / both	Responsibility of the tasks "annual crops"	Responsibility of the tasks "annual crops"
PerenCrop	female / male / both	Responsibility of the tasks "perennial crops"	Responsibility of the tasks "perennial crops"
Harvest	female / male / both	Responsibility of the tasks "harvest of crops"	Responsibility of the tasks "harvest of crops"
DecHarvest	female / male / both	Responsibility of the tasks "decision about the harvested crops"	Responsibility of the tasks "decision about the harvested crops"
LSKeep	female / male / both	Responsibility of the tasks "livestock-keeping"	Responsibility of the tasks "livestock-keeping"
DecAniProd	female / male / both	Responsibility of the tasks "decision on animal products"	Responsibility of the tasks "decision on animal products"
SellProd	female / male / both	Responsibility of the tasks "selling products"	Responsibility of the tasks "selling products"
BuyFood	female / male / both	Responsibility of the tasks "buying food"	Responsibility of the tasks "buying food"
WorkOn	female / male / both	Responsibility of the tasks "working on the own farm"	Responsibility of the tasks "working on the own farm"
WorkOff	female / male / both	Responsibility of the tasks "working off-farm"	Responsibility of the tasks "working off-farm"
Cook	female / male / both	Responsibility of the tasks "cooking"	Responsibility of the tasks "cooking"
Store	female / male / both	Responsibility of the tasks "storing food"	Responsibility of the tasks "storing food"
Water	female / male / both	Responsibility of the tasks "collecting and caring for drinking water"	Responsibility of the tasks "collecting and caring for drinking water"
Wash	female / male / both	Responsibility of the tasks "washing"	Responsibility of the tasks "washing"
Toil	female / male / both	Responsibility of the tasks "toilet cleaning"	Responsibility of the tasks "toilet cleaning"

Table A 11: Data of gender-specific distribution of tasks within the farming families.

QID	SeedsOwn	SeedsExch	WeedCon/Till	Terr	OMField	AnuCrop	PerenCrop	Harvest	DecHarvest	LSKeep
1	Both	Female	Both	Both	Both	Female	Both	Both	Both	Both
2	Both	We don't do this.	Both	We don't do this.	Both	Both	Both	Both	Both	Both
3	Female	We don't do this.	Female	Female	Female	Female	Female	Female	Female	Female
4	Both	Both	Both	Both	Both	Male	Female	Both	Both	Both
5	Female	We don't do this	Both	We don't do this.	We don't do this.	Male	Both	Both	Both	Both
6	Both	Both	Both	We don't do this.	We don't do this.	Both	Both	Both	Both	Both
7	Both	Female	Both	Female	Both	Female	Female	Both	Both	Both
8	Both	We don't do this.	Both	Both	We don't do this.	Both	Both	Both	Both	Both
9	Female	Male	Both	Male	Male	Both	Both	Both	Both	Both
10	Both	Female	Both	Both	Both	Both	Both	Both	Both	Both
11	Both	Both	Both	Both	Both	Male	Both	Both	Both	Both
12	Both	We don't do this.	Both	We don't do this.	Male	Male	Both	Both	Both	Both
13	Male	Female	Both	Male	Male	Both	Female	Both	Both	Both
14	Female	Female	Female	We don't do this	Female	Female	Female	Female	Female	Female
15	Female	Both	Both	We don't do this.	Both	Male	Both	Both	Both	Both
16	Both	We don't do this.	Both	Both	Both	Female	Both	Both	Both	Both
17	Both	Female	Both	Male	Male	Both	Both	Both	Male	Male
18	Both	Both	Both	Male	Male	Both	Both	Both	Both	Male
19	Female	Female	Female	Female	We don't do this	Female	Female	Female	Female	Female
20	Both	Both	Both	We don't do this.	Both	Both	Both	Both	Both	We don't do this.
21	Both	Male	Both	Both	Male	Both	Both	Both	Both	Both
22	Female	Female	Both	Male	Male	Male	Female	Both	Both	Female
23	Both	Female	Both	Both	Both	Male	Both	Both	Both	Female
24	Both	We don't do this.	Both	Female	We don't do this.	Male	Both	Both	Both	Both
25	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both
26	Male	Male	Male	We don't do this.	Male	Male	Male	Male	Male	Male
27	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both
28	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
29	Both	We don't do this.	Both	Both	Both	Male	Both	Both	Both	Male
30	Both	Female	Both	Both	Both	Male	Both	Both	Both	Both
31	Female	Female	Female	Female	Male	Male	Female	Female	Male	Female

QID	SeedsOwn	SeedsExch	WeedCon/Till	Terr	OMField	AnuCrop	PerenCrop	Harvest	DecHarvest	LSKeep
32	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both
33	Both	Both	Both	Both	We don't do this.	Both	Both	Both	Both	Both
34	Both	Female	Both	We don't do this.	Male	Male	Female	Female	Both	Female
35	Both	Both	Both	Male	Male	Male	Both	Both	Male	Both
36	Female	Female	Female	Female	Female	Female	Female	Female	Both	Female
37	Both	Female	Both	Both	Both	Male	Both	Both	Both	Female
38	Female	Female	Both	Both	Female	Female	Female	Both	Both	Female
39	Both	Both	Both	Both	Both	Both	Both	Both	Male	Male
40	Both	We don't do this.	Both	Both	Both	Male	Both	Both	Female	Female
41	Both	Female	Both	Both	Male	Both	Both	Both	Both	We don't do this.
42	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both
43	Female	Female	Female	Female	Female	Female	Female	Female	Female	We don't do this.
44	Both	Female	Both	Male	Both	Both	Both	Both	Both	Both
45	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
46	Female	Female	Both	Female	Female	Both	Both	Female	Male	Female
47	Female	Female	Female	Female	We don't do this.	We don't do this.	Female	Female	Female	Female
48	Female	Female	Female	Male	Both	Both	Female	Female	Female	Both
49	Both	Both	Both	We don't do this.	We don't do this.	Both	Both	Both	Both	We don't do this.
50	Female	Female	Both	Both	Male	Female	Female	Both	Female	Female
51	Both	Female	Both	Both	Both	Both	Both	Both	Female	Both
52	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both
53	Female	Female	Female	Female	Female	Male	Female	Female	Female	Male
54	Both	Male	Both	Both	Male	Male	Both	Both	Both	Both
55	Both	Female	Both	We don't do this.	Both	Male	Both	Both	Both	Both
56	Both	Female	Both	Both	Both	Male	Both	Both	Both	We don't do this.
57	Female	Female	Both	Both	Male	Male	Female	Both	Both	Male
58	Both	Both	Both	We don't do this.	Both	Both	Both	Both	Both	Male
59	Both	Both	Both	Both	We don't do this.	Male	Both	Both	Both	Both
60	Both	We don't do this.	Female	We don't do this.	Female	Female	Female	Female	Female	Both
61	Both	We don't do this.	Both	We don't do this.	Male	Male	Both	Both	Both	Both
62	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
63	Both	Both	Both	Male	Male	Male	Both	Both	Both	Female

QID	SeedsOwn	SeedsExch	WeedCon/Till	Terr	OMField	AnuCrop	PerenCrop	Harvest	DecHarvest	LSKeep
64	Both	Both	Both	We don't do this.	We don't do this.	Both	Both	Both	Female	Both
65	Both	We don't do this.	Both	Both	Male	Both	Both	Both	Both	Both
66	Both	Male	Both	Both	Male	Male	Both	Both	Male	Male
67	Both	We don't do this.	Both	We don't do this.	Male	Male	Female	Both	Both	Female
68	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both
69	Female	Male	Both	We don't do this.	We don't do this.	Both	Both	Both	Both	Both
70	Both	Female	Both	Both	Both	Male	Both	Both	Both	Both
71	Both	Both	Both	Both	Both	Both	Both	Both	Both	We don't do this.
72	Both	Both	Both	We don't do this.	Male	Male	Both	Both	Both	Male
73	Both	Female	Both	We don't do this.	We don't do this.	We don't do this.	Female	Both	Both	Both
74	Female	Female	Female	Female	We don't do this.	Female	Female	Female	Female	Female
75	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
76	Both	Female	Both	Both	We don't do this.	Female	Both	Both	Female	Both
77	Female	Female	Female	We don't do this.	Female	Female	Female	Female	Female	We don't do this.
78	Female	Female	Female	Female	Female	Male	Female	Female	Female	Female
79	Both	Male	Both	Both	Both	Both	Both	Both	Both	Both
80	Both	We don't do this.	Both	Both	Both	Both	Both	Both	Both	Both
81	Both	Female	Both	Both	Both	Both	Both	Both	Both	Both
82	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both
83	Both	Both	Both	Both	We don't do this.	Both	Both	Both	Both	We don't do this.
84	Female	We don't do this.	Female	Female	Female	Female	Female	Female	Female	Female
85	Female	Female	Both	Both	We don't do this.	Both	Female	Both	Both	Both
86	Both	Both	Both	Both	Both	Female	Both	Both	Both	Both
87	Male	Male	Both	We don't do this.	We don't do this.	Female	Female	Male	Female	Female
88	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
89	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both
90	Both	We don't do this.	Both	Both	Both	Both	Both	Both	Both	Both
91	Female	Female	Female	Female	Female	Female	Female	Female	Female	We don't do this.
92	Male	Male	Male	Male	We don't do this.	Male	Male	Male	Male	Male
93	Both	Female	Both	Male	Male	Male	Female	Both	Both	Both
94	Both	Female	Both	Male	Male	Male	Female	Both	Both	Both
95	Female	Female	Both	Both	Both	Both	Both	Both	Both	We don't do this.

QID	SeedsOwn	SeedsExch	WeedCon/Till	Terr	OMField	AnuCrop	PerenCrop	Harvest	DecHarvest	LSKeep
96	Female	We don't do this.	Female		Female	Female	Female	Female	Female	Female
97	Both	Both	Both	Both	Both	Male	Both	Both	Both	Both
98	Female	We don't do this.	Female	Female	Female	Female	Female	Female	Female	Female
99	Both	We don't do this.	Both	Both	Both	Both	Both	Both	Both	Both
100	Both	Female	Both	We don't do this.	Female	Male	Female	Both	Both	Female
101	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
102	Female	Female	Both	We don't do this.	Both	Male	Female	Both	Both	Both
103	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both
104	Female	Female	Female	Female	Male	Male	Female	Female	Both	Male
105	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
106	Female	Female	Female	We don't do this.	Female	Female	Female	Female	Female	Female
107	Both	Both	Both	We don't do this.	Both	Male	Female	Both	Both	Both
108	Both	Both	Both	Both	Male	Female	Both	Both	Both	Both
109	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both
110	Both	Female	Both	Both	We don't do this.	Male	Female	Both	Both	Both
111	Both	Female	Both	Male	Both	Both	Both	Both	Both	Both
112	Both	We don't do this.	Both	Both	Both	Both	Both	Both	Male	Both
113	Both	Both	Both	Both	Male	Both	Both	Both	Male	Both
114	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both
115	Both	Both	Both	Both	Both	Male	Female	Both	Male	Both
116	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both
117	Both	Female	Both	Both	Both	Both	Both	Both	Both	Male
118	Both	Female	Both	Both	Both	Both	Both	Both	Both	We don't do this.
119	Female	Female	Female	We don't do this.	We don't do this.	Female	Female	Female	Female	Female
120	Female	Female	Both	Both	Both	Both	Female	Both	Both	Both
121	We don't do this.	We don't do this.	Female	We don't do this.	Female	Female	Female	Female	Female	Female
122	Both	Both	Both	We don't do this.	Both	Both	Both	Both	Both	Both
123	Both	We don't do this.	Both	We don't do this.	We don't do this.	Both	Both	Both	Both	Both
124	Both	Both	Both	Female	Both	Male	Both	Both	Both	Female
125	Both	Male	Both	We don't do this.	We don't do this.	Both	Both	Both	Both	Both
126	Female	We don't do this.	Both	Both	Both	Both	Both	Both	Both	Both
127	Both	Both	Both	We don't do this.	We don't do this.	Both	Both	Both	Both	Both

QID	SeedsOwn	SeedsExch	WeedCon/Till	Terr	OMField	AnuCrop	PerenCrop	Harvest	DecHarvest	LSKeep
128	Both	Both	Both	Both	Male	Both	Both	Both	Both	We don't do this.
129	Male	We don't do this.	Both	Both	Male	Male	Female	Both	Male	Both
130	Both	We don't do this.	Both	Both	Both	Both	Both	Both	Both	Both
131	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both
132	Both	We don't do this.	Both	Both	Both	Both	Both	Both	Both	Both
133	Both	Both	Both	Both	We don't do this.	Both	Both	Both	Both	We don't do this.
134	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
135	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
136	Both	We don't do this.	Both	Both	Both	Both	Both	Both	Both	Both
137	Both	Both	Both	Both	Both	Male	Both	Both	Both	Both
138	Both	Both	Both	Both	Male	Male	Both	Both	Both	Both
139	Both	Both	Both	Both	Male	Male	Both	Both	Both	Both
140	Both	Female	Both	Both	Male	Male	Both	Both	Both	Both
141	Both	Male	Both	Both	Both	Male	Both	Both	Both	Both
142	Both	Both	Both	Both	Both	Male	Both	Both	Both	We don't do this.
143	Both	Female	Both	Both	Both	Both	Both	Both	Both	Both
144	Both	We don't do this.	Both	Both	Male	Male	Both	Both	Both	We don't do this.
145	Both	Both	Both	Both	We don't do this.	Both	Both	Both	Both	Both
146	Female	Female	Female	Female	Female	Male	Female	Female	Both	Female
147	Female	We don't do this.	Female	Female	Female	Female	Female	Female	Female	Female
148	Female	Female	Female	Female	Female	Male	Female	Female	Both	Both
149	Both	Female	Both	Both	Both	Male	Both	Both	Both	Both
150	Both	Both	Both	Female	Male	Male	Both	Both	Both	Both

Table A-11 cont.: Data of gender-specific distribution of tasks within the surveyed farming families.

QID	DecAniProd	SellProd	BuyFood	WorkOn	WorkOff	Cook	Store	Water	Wash	Toil
1	Both	Both	Both	Both	Both	Female	Both	Female	Female	Female
2	Both	Both	Both	Both	Male	Female	Both	Both	Female	Both
3	Female	Female	Female	Female	Female	Female	Female	Both	Female	Female
4	Both	Both	Both	Both	Both	Female	Female	Female	Female	Both
5	Both	Both	Female	Both	We don't do this.	Female	Both	Female	Female	Female

QID	DecAniProd	SellProd	BuyFood	WorkOn	WorkOff	Cook	Store	Water	Wash	Toil
6	Both	Both	Both	Both	Male	Female	Female	Female	Female	Female
7	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
8	Both	Both	Male	Both	We don't do this.	Female	Male	Female	Female	Both
9	Both	Male	Male	Both	Male	Female	Female	Female	Female	Female
10	Both	Both	Female	Both	Both	Female	Female	Female	Female	Both
11	Both	Both	Male	Both	We don't do this.	Female	Female	Male	Female	Female
12	Both	Female	Female	Both	Male	Female	Female	Female	Female	Female
13	Both	Both	Male	Both	Male	Female	Female	Female	Female	Male
14	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
15	Both	Both	Female	Both	Both	Female	Female	Female	Female	Female
16	Both	Both	Both	Both	Both	Female	Both	Female	Female	Both
17	Both	Male	Male	Both	Male	Female	Female	Female	Female	Female
18	Both	Both	Male	Both	Both	Female	Both	Female	Female	Female
19	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
20	We don't do this.	Both	Both	Both	Both	Both	Both	Both	Female	Female
21	Both	Both	Female	Both	We don't do this.	Female	Male	Both	Both	Female
22	Male	Female	Male	Both	Female	Female	Female	Female	Female	Female
23	Both	Both	Female	Both	Both	Female	Female	Female	Female	Female
24	Both	Both	Female	Both	Male	Female	Female	Female	Female	Both
25	Both	Both	Both	Both	Both	Both	Both	Both	Female	Both
26	We don't do this.	Male	Male	Male	Male	Male	Male	Male	Male	Female
27	Both	Both	Both	Both	Both	Female	Both	Both	Both	Both
28	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
29	Male	Both	Both	Both	We don't do this.	Female	Both	Female	Female	Both
30	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both
31	Male	Female	Male	Female	Male	Female	Female	Female	Female	Female
32	Both	Both	Both	Both	Both	Female	Both	Both	Female	Female
33	Both	Both	Male	Both	Both	Female	Female	Male	Female	Female
34	Both	Both	Male	Both	Both	Female	Female	Female	Female	Female
35	Both	Both	Male	Both	Male	Female	Both	Female	Female	Female
36	Male	Male	Male	Both	Both	Female	Female	Female	Female	Female
37	Female	Female	Both	Both	Both	Female	Both	Female	Female	Female

QID	DecAniProd	SellProd	BuyFood	WorkOn	WorkOff	Cook	Store	Water	Wash	Toil
38	Both	We don't do this.	Both	Female	Female	Female	Female	Female	Female	Female
39	Male	Male	Male	Both	Male	Female	Male	Female	Female	Female
40	Female	Both	Both	Both	Both	Both	Female	Female	Female	Female
41	We don't do this.	Both	Male	Both	Both	Female	Both	Female	Female	Female
42	Both	Both	Both	Both	Male	Female	Both	Female	Female	Female
43	We don't do this.	Female	Female	Female	Female	Female	Female	Female	Female	Female
44	Both	Female	Female	Both	Male	Female	Female	Female	Female	Female
45	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
46	Male	Male	Both	Both	Female	Female	Female	Female	Female	Female
47	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
48	Both	Both	Both	Female	Male	Female	Female	Both	Both	Both
49	Both	Male	Male	Both	Male	Female	Female	Female	Both	Female
50	Female	Female	Female	Female	We don't do this.	Female	Female	Female	Female	Female
51	Female	Female	Female	Both	We don't do this.	Female	Female	Both	Both	Both
52	Both	Both	Female	Both	Both	Female	Both	Both	Female	Female
53	Both	Female	Female	Both	Both	Female	Female	Female	Female	Female
54	Both	Both	Male	Both	Male	Female	Both	Both	Both	Both
55	Both	Both	Both	Both	Male	Female	Female	Female	Female	Female
56	We don't do this.	Female	Both	Both	Male	Female	Female	Female	Female	Female
57	Both	Both	Female	Both	Male	Female	Both	Female	Female	Female
58	Both	Both	Both	Both	Male	Female	Both	Female	Female	Female
59	Both	Both	Both	Both	Male	Female	Female	Female	Female	Female
60	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
61	Both	Male	Both	Both	Both	Female	Female	Female	Female	Female
62	Female	Both	Female	Female	Both	Female	Female	Both	Both	Both
63	Both	Both	Both	Both	Male	Female	Female	Female	Female	Female
64	Female	Both	Both	Both	Both	Both	Female	Both	Both	Both
65	Both	Both	Both	Both	We don't do this.	Female	Both	Both	Female	Both
66	Both	Male	Male	Both	Male	Female	Female	Female	Female	Female
67	Both	Both	Female	Both	Both	Female	Female	Female	Female	Female
68	Both	Both	Male	Both	Male	Female	Female	Female	Female	Female
69	Both	Both	Both	Both	Both	Female	Both	Female	Female	Female

QID	DecAniProd	SellProd	BuyFood	WorkOn	WorkOff	Cook	Store	Water	Wash	Toil
70	Both	Both	Both	Both	Male	Female	Both	Female	Female	Female
71	Both	Both	Both	Both	Both	Female	Both	Both	Female	Female
72	Both	Female	Female	Both	Male	Female	Female	Female	Female	Female
73	We don't do this.	Both	We don't do this.	Both	We don't do this.	Female	Female	Female	Female	Female
74	Female	Female	Female	Female	We don't do this.	Female	Female	Female	Female	Female
75	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
76	Female	Female	Female	Both	We don't do this.	Female	Female	Female	Both	Both
77	We don't do this.	We don't do this.	Female	Female	Female	Female	Female	Female	Female	Female
78	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
79	Both	Both	Both	Both	We don't do this.	Female	Female	Female	Female	Female
80	Both	Both	Male	Both	Male	Female	Both	Female	Female	Female
81	Both	Both	Both	Both	Both	Female	Both	Both	Female	Both
82	Both	Both	Both	Both	We don't do this	Both	Both	Female	Female	Female
83	Both	Both	Both	Both	We don't do this.	Female	Female	Female	Female	Female
84	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
85	Both	Both	Both	Both	Male	Female	Female	Female	Female	Female
86	Both	Both	Female	Both	Both	Female	Female	Female	Female	Both
87	Female	Male	Female	Both	We don't do this.	Female	Female	Male	Female	Female
88	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
89	Both	Both	Both	Both	Both	Female	Female	Female	Female	Female
90	Both	Both	Both	Both	Both	Female	Female	Female	Female	Female
91	We don't do this.	We don't do this.	Female	Female	Female	Female	Female	Female	Female	Female
92	Male	Male	Male	Male	Male	Male	Male	Male	Male	Male
93	Both	Both	Both	Both	Both	Female	Both	Both	Female	Female
94	Both	Both	Male	Both	Both	Female	Both	Female	Female	Female
95	We don't do this.	Both	Both	Both	Male	Female	Female	Female	Female	Female
96	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
97	Both	Both	Both	Both	Male	Female	Female	Female	Female	Female
98	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
99	Both	Both	Both	Both	Male	Female	Female	Female	Female	Female
100	Both	Both	Female	Both	Female	Female	Female	Both	Female	Female
101	Female	We don't do this.	Female	Female	Female	Female	Female	Female	Female	Female

QID	DecAniProd	SellProd	BuyFood	WorkOn	WorkOff	Cook	Store	Water	Wash	Toil
102	Male	Female	Male	Both	Male	Female	Female	Female	Female	Female
103	We don't do this.	We don't do this.	Both	Both	Both	Both	Both	Female	Female	Both
104	Male	Both	Female	Female	Male	Female	Female	Female	Female	Female
105	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
106	Female	Female	Female	Female	We don't do this.	Female	Female	Female	Female	Female
107	Both	Both	Both	Both	We don't do this.	Female	Female	Female	Female	Female
108	Both	Male	Both	Both	Both	Female	Female	Female	Female	Female
109	Both	Both	Both	Both	Male	Female	Female	Female	Female	Both
110	Both	Both	Female	Both	Male	Female	Female	Female	Female	Female
111	Both	Both	Female	Both	Male	Female	Female	Female	Female	Female
112	Male	Both	Both	Both	Male	Female	Both	Female	Female	Male
113	Both	Both	Both	Both	Both	Female	Female	Female	Female	Both
114	Both	Both	Both	Both	Both	Female	Both	Both	Female	Both
115	Male	Both	Both	Both	Both	Female	Female	Female	Female	Female
116	Both	Both	Both	Both	Both	Female	Female	Female	Female	Female
117	Both	Both	Female	Both	Male	Female	Female	Female	Female	Female
118	We don't do this.	Both	Both	Both	Both	Female	Female	Female	Female	Female
119	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
120	Both	Both	Male	Both	Both	Female	Female	Female	Female	Female
121	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
122	Both	Both	Both	Both	Both	Both	Both	Both	Female	Both
123	Both	We don't do this.	Male	Both	Male	Female	Both	Both	Female	Both
124	Both	Male	Male	Both	Male	Female	Female	Female	Female	Female
125	Both	Both	Male	Both	We don't do this	Female	Both	Both	Female	Female
126	Both	Both	Female	Both	Both	Female	Female	Female	Female	Female
127	Both	Both	Both	Both	Both	Female	Female	Both	Female	Female
128	Both	Both	We don't do this.	Both	Male	Female	Female	Female	Female	Female
129	Both	Male	Male	Both	Female	Female	Female	Female	Female	Female
130	Both	Both	Both	Both	We don't do this.	Female	Both	Both	Female	Female
131	Both	Both	Both	Both	Male	Female	Both	Female	Female	Female
132	Both	Both	Both	Both	Both	Female	Both	Both	Female	Both
133	We don't do this.	Both	Both	Both	We don't do this.	Female	Female	Female	Female	Female

QID	DecAniProd	SellProd	BuyFood	WorkOn	WorkOff	Cook	Store	Water	Wash	Toil
134	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
135	Female	Female	Female	Female	Female	Female	Female	Female	Female	Female
136	Both	Both	Both	Both	Female	Female	Female	Female	Female	Female
137	Both	Both	Both	Both	Both	Both	Both	Both	Both	Both
138	Both	Both	Both	Both	Both	Female	Both	Female	Female	Female
139	Both	Both	Female	Both	We don't do this.	Female	Both	Female	Female	Both
140	Male	Both	Female	Both	Male	Female	Female	Female	Female	Female
141	Both	Both	Both	Both	Both	Female	Both	Female	Female	Female
142	We don't do this.	We don't do this.	Both	Both	Both	Female	Female	Female	Female	Female
143	Both	Both	Both	Both	Both	Female	Female	Female	Female	Female
144	We don't do this.	We don't do this.	Both	Both	Both	Female	Female	Female	Female	Female
145	Both	Both	Both	Both	Female	Female	Both	Both	Female	Female
146	Both	Both	Male	Both	Male	Female	Female	Female	Female	Female
147	Female	Female	We don't do this.	Female	Female	Female	Female	Female	Female	Female
148	Both	Both	Female	Female	Female	Female	Female	Female	Female	Female
149	Both	Both	Both	Both	Both	Female	Female	Both	Female	Both
150	Both	Both	Both	Both	We don't do this.	Female	Female	Both	Both	Both

The end of the record.